A MODEL TO INTEGRATE THE MANAGEMENT OF HAZARDS AND DISASTERS IN THE NATIONAL SUSTAINABLE DEVELOPMENT PLANNING OF THE MALDIVES

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Degree

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Glossary

Inhabited Islands	Inhabited islands are populated and have an administration office which takes the responsibility of taking care of the community on the island
Uninhabited Islands	All islands except the inhabited islands
Atoll	Two definitions of the atolls have been used in this thesis; natural atoll: (i) 26 shallow areas in the middle of ocean which are surrounded by coral reefs and administrative atolls, (ii) 20 atolls for the administrative purposes of the Government of Maldives
Reef	A rock or an area or feature beneath the surface of the water and exposed at the mean tide.
Natural Island Vulnerability	A feature of the island which makes the island exposed to a flooding event caused by a natural disaster due to its geographic and geomorphologic characteristics
Building Vulnerability	The features of a building on an island which makes the building vulnerable to a flooding event caused by a natural disaster.
Human Vulnerability	The vulnerability of the community of an island to a flooding event caused by a natural disaster due to natural vulnerability of the island and the building vulnerability of the buildings on the island
Island Vulnerability Index	A composite index made of 'Natural Island Vulnerability', 'Building Vulnerability' and 'Human Vulnerability' which gives an indication of the vulnerability of an island to a flooding event caused by a natural disaster
Safer Island	An island which is developed as an urban centre and has a low risk for a disaster by enhancing the natural protection on the island
Base map	The map of Maldives showing outlines of the islands for geographic reference; thematic information generated has been superimposed.
Regression	The study of the dependence of one variable (the dependent variable), on one or more other variables (the explanatory variables), with a goal of estimating the mean value of the former in terms of the known or fixed values of the latter.
Resilience	The capacity of a community potentially exposed to hazards to adapt by resisting, reaching and maintaining an acceptable level of functioning and structure.

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ABSTRACT

The small land area of the islands of the Maldives, combined with high population density, makes the communities of these islands vulnerable to natural disaster events such as flooding and tsunami. The Indian Ocean Tsunami on 26 December 2004 impacted 69 islands of the Maldives, killing 82 people, leaving 26 people missing and 15, 000 people internally displaced, making it the worst disaster in recorded history. Following the event, the Government of the Maldives announced a Safer Island Development Programme which seeks to provide the infrastructure necessary to adapt to natural disasters.

The key focus of disaster management is to reduce the vulnerability of the communities exposed to hazards and risks, and to help them to enhance their resilience. Efforts have been made to develop safer and sustainable communities in all corners of the developed and developing worlds. New Zealand Government announced its effort to build safe and secure communities in 2007 while at a local level the Christchurch City Council published the Safer Christchurch Strategy in 2005. Overseas, the Community Strategy 2000, outlines the vision of "A safe and strong Island" at Isle of Wight United Kingdom.

The islands of the Maldives have natural characteristics which make them vulnerable to disasters such as tsunami. This research has been able to identify the relationship between these characteristics and the *natural vulnerability* of the islands using the data that was collected following the Indian Ocean Tsunami. Out of 11 island, that have been identified for the Safer Islands Development Programme, one island is found to have very high natural vulnerability and 5 islands a high natural vulnerability, from the island vulnerability index model developed through this study.

The Island Vulnerability Index model could be used to enhance the present Safer Island Development Programme island selection criteria, to reduce the possibility of 'building risk' into the infrastructure development on the islands. The index could also be used in the Environmental Impact Assessment studies to address the issue of disasters, effective resources allocation in the Public Sector Infrastructure Programme for '*building back better'*, and resource identification in land use planning.

1 INTRODUCTION

When people first settled in the Maldives, they preferred some islands over others to live on. This choice was greatly influenced by environmental factors such as the availability of fresh water, geographic location of the island and social factors such as the difficulty for pirates to get access to the island. The Maldivians like to live on islands where there is fresh ground water, that do not have natural harbour (and hence pirates will not be able to access the island easily) and islands that are located close to major fishing grounds which can be reached by their sail dhonies[1]. Other than in the last two decades, the contemporary history of the Maldives has not recorded a natural disaster that had a major impact on the country.

The greater advancement of technology in the past two decades has facilitated greater physical development in the Maldives that was not possible previously. The development of explosives and excavation technology has facilitated changing the natural contours of the sea floor, as large areas on shallow lagoons have been excavated. Large areas of reef can be converted into lands by reclamation, and hence causing a change in the natural shape of the islands. Harbours could be developed on any area of the reef by dynamiting hard sections of the reef and excavating the area. The unchecked development that has modified the natural environment has led to natural disasters in the Maldives recently.

This research has been initiated following the unveiling of the Safer Island Development Programme[2] (SIDP) in the Maldives following the Indian Ocean Tsunami of December 2004, that caused widespread damage to the natural, built and human environment of the Maldives. Natural events such as tsunamis have a physical 'signature' which can help to predict the long-term response of a natural system. It is important to capture this 'signature' and integrate it into the physical development of the islands as this could facilitate working with natural systems rather than against them.

[1] Dhonies are boats like structures built from locally available timber used for the transportation of people from one island to another.

[2] For details of the programme refer to section 4.5.1.5

1.1 Goals and objectives

This research looks into the natural vulnerability of the small low-lying islands of the Maldives. The goal of the work is to develop a model that can help as a tool to integrate disaster risk reduction into development planning. The key objective of the research is to develop a set of indicators which can be used to assess the natural vulnerability of the islands by looking at the impacts of the Indian Ocean Tsunami. The indicators will be used to develop a model to identify physically vulnerable islands. Then it will look further into the Safer Island Development Programme which is currently being undertaken in the Maldives as part of the Tsunami Recovery and Reconstruction to see whether the programme is on the track of 'building back better' or 'building the risk into system'.

1.2 Thesis Organisation

This thesis comprises six chapters.

Chapter 1 gives a background to the Maldives by giving a brief introduction to the geography, morphology, physical, social and built environment of the Maldives.

Chapter 2 gives a brief background to the Indian Ocean Tsunami of 26 December 2004 and its impact on the natural, physical and social environment of the Maldives.

Chapter 3 gives an overview of the integrated disaster management models that are globally being used in the context of disaster mitigation. This chapter also provides details of the Safer Community approaches that are being used in New Zealand and UK. The Safer Island Development Programme of the Maldives is also described in this chapter.

Chapter 4 presents detailed aims and objective of the study and outlines the study methodology. The chapters present the model which integrates the management of critical disasters in the Sustainable Development Planning of the Maldives.

Chapter 5 presents the research findings which details the impact of the Indian Ocean Tsunami on the islands of the Maldives.

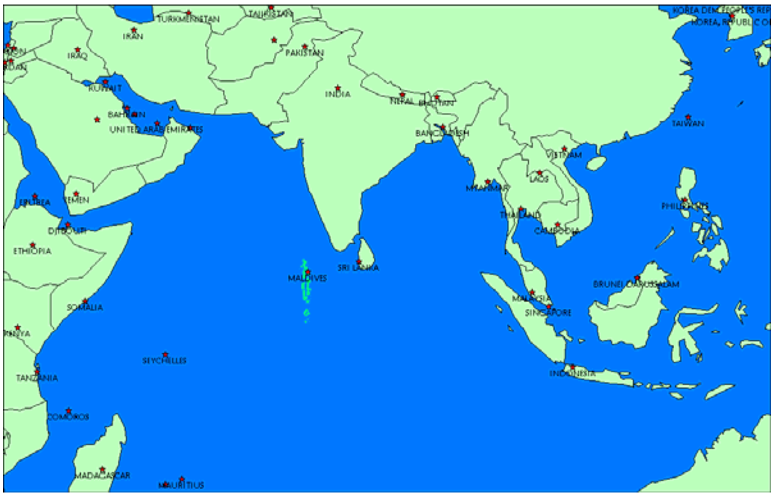
Chapter 6 presents conclusions and recommendation which could be used to enhance the island selection criteria of the Safer Island Development Programme.

2 THE MALDIVES

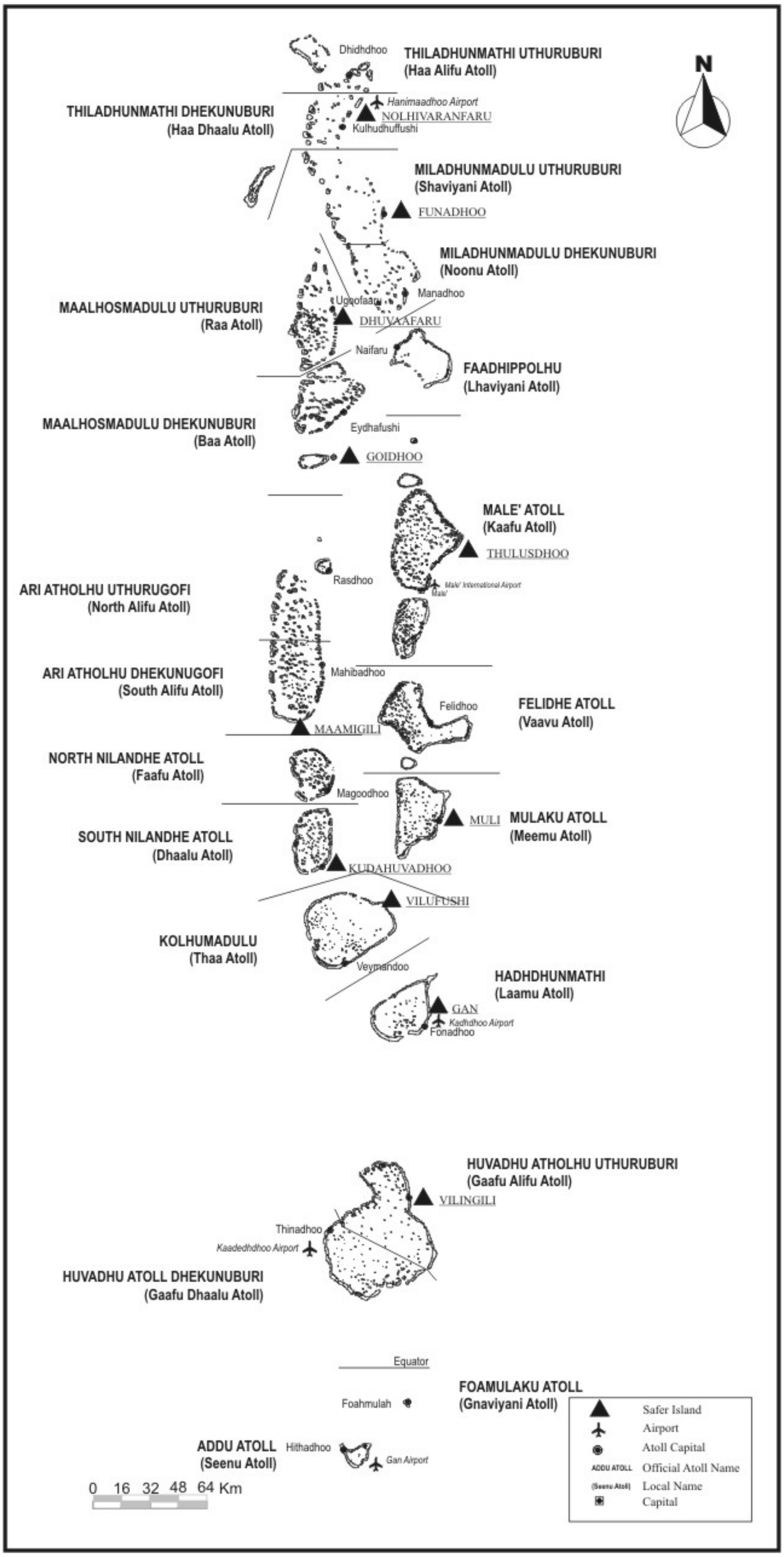
This chapter will give a background to the Maldives by providing a brief introduction to the geography, morphology, physical, social and built environment of the Maldives to provide a context of the island's vulnerability to natural disasters. This chapter will also provide a profile of the natural disasters experienced in the Maldives.

2.1 Geography

The Republic of Maldives is the sixth smallest sovereign state in the world in terms of land area with an estimated 235km^2 of land, divided over 1190 islands (2007b). The Maldives is a chain of coral atolls in the Indian Ocean stretching 900 km from latitude 7^{0}6' 35"N crossing the Equator to 00º 45'S and 72º 33' E to 73º 47'E longitude. Its nearest neighbours are India, Sri Lanka and Chagos Islands, lying approximately 600 and 750 km to the north and north-east, and immediately south respectively (Naseer, 2003). The width of the chain varies from 80 to 130 km. The maritime area of the Exclusive Economic Zone (EEZ) of the Maldives amounts to 859, 000 km^2 (MPND, 2000).



Map 1: Location of the Republic of Maldives in the Indian Ocean (source: MHAHE, 2001)



Map 2: Map of the Maldives (source: MEEW, 2007)

2.2 Geology

The islands of the Maldives occupy the central 700 km – long portion of the 3000 km – long Lacadive- Chargos submarine ridge, where they form a double chain of north-south orientated parallel atolls separated by an inner sea. The atolls rest on a submarine plateau that is 275 to 700 m deep, 700 km long and up to 130 km wide. There are several east-west trending deep (~1000 m) channels separating atoll groups.

The islands are low-lying Holocene features that began forming between 3000 and 5500 years ago (Woodroffe, 1992). The islands represent the most recent deposition along a submarine plateau that is underlain by approximately 2100 meters of mostly shallow-water carbonates resting on a slowly-subsiding Eocene volcanic foundation (Purdy, 1981).

The islands are composed primarily of reef-derived carbonate sediment that has been deposited by waves and currents. The geomorphology of the islands has been discussed by Stodddart (1996), Woodroffe (1992) and Kench et al. (2005). In simple terms the islands tend to be either (1) seaward-edge islands on the peripheral atoll rim formed of sand and gravel with steep, coarse beaches along their seaward margins and sand beaches along their lagoon (protected) shores, (2) lagoon-edge islands composed mostly of sand with minor amounts of gravel, and (3) sand – cay type islands which form both on peripheral rims and within lagoonal reef top settings (Richmond et al., 2006). Land elevation is generally less than 2 m above mean sea level. Because of their unconsolidated nature, the islands are considered ephemeral features over geological timescales and their low elevation makes them particularly vulnerable to changes in sea level (Richmond et al., 2006).

Island shorelines consist of sand, gravel, and a variety of engineering structures. The country's beach systems are highly dynamic and subject to seasonal conditions, especially from monsoons. Although the Maldives is located away from the main pathways of tropical cyclones, the presence of gravel beach ridges and cemented conglomerates attest to the fact that storm waves are an important element in the development of the islands (UNEP, 2005) .

Erosion and accretion are, in fact, ongoing processes to which local communities have adapted in the past. Increases in population and the development of permanent infrastructure in close proximity to shorelines, however, have made erosion a prominent hazard to the country's social and economic well-being (UNEP, 2005).

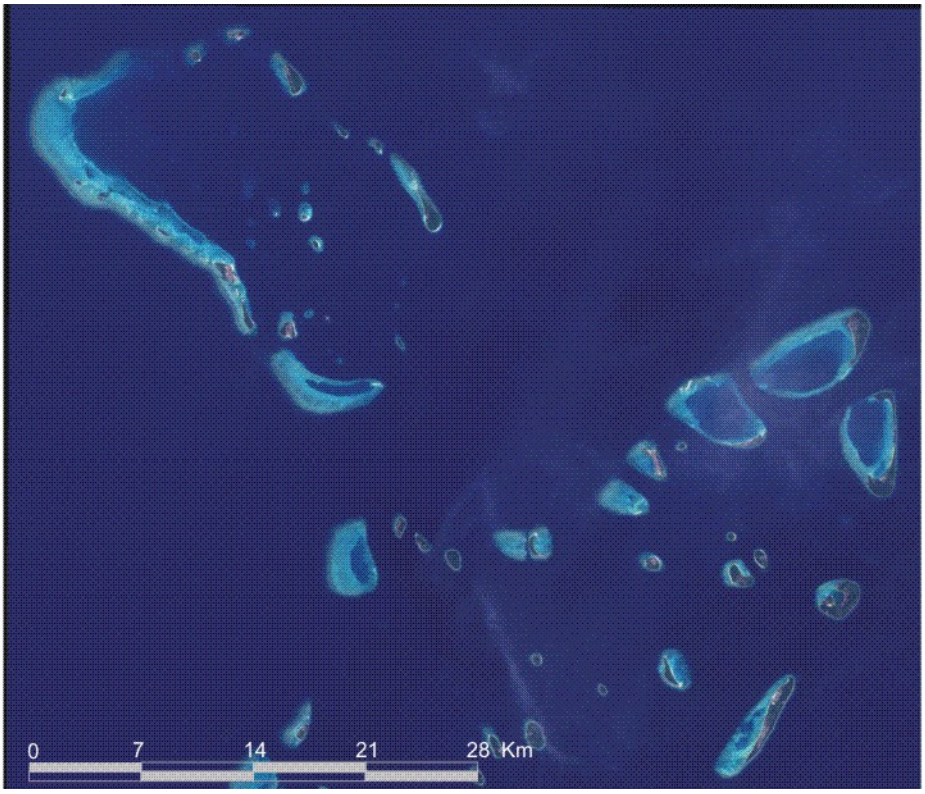
It is estimated that 80% of the islands are one metre or less above sea level (MHAHE, 2001). Their low elevation makes them particularly vulnerable to storms and changes in sea level. The prospect of global sea level rise and its potentially catastrophic impact on low-lying islands makes erosion management all the more urgent (UNEP, 2005).

2.2.1 Atolls – Building Blocks of the Maldives

The archipelago contains 26 geographic atolls, which vary in shape and size. Double chain of atolls in the central region, tapering off towards the north and south to single atolls can be seen on Map 2. Map 3 shows a typical Maldivian atoll. Atoll rim reefs of the Maldives display asymmetric geomorphology; reefs on the ocean-ward rims of the atolls have wider and more extensive reef flats than those lining the rim facing the sea between line of the atolls (Guilcher, 1988).

The sizes of the atolls vary from 1.4 to 2800 km^2. The largest atoll in Maldives is Thiladhunmathi Atoll with a total surface area of 3,788 km^2. Huvadhoo Atoll is the second largest with a total surface area of 3,278 km^2. Thiladhunmathi Atoll has the largest reef area (approximately 500 km^2) while Ari Atoll has the second largest with 489 km^2 approximately (Naseer et al., 2004). It is estimated that the atolls of the Maldives are over 5,000 years old (Woodroffe, 1989).

These atolls are grouped into 20 administrative regions. The capital Malé forms a separate administrative unit and is centrally located. The distances between different atolls vary from 1.5 km in the channel between Kuda Kanduolhi and Kudarikilu Kandu in Baa Atoll and 96 km in the Huvadhoo Kandu (one and half degree located between 3^{rd} and 4^{th} atoll from the bottom on Map 2).



Map 3: Haa Alifu Atoll – a aerial view of a typical Atoll of the Maldives (Source: Google, 2007)

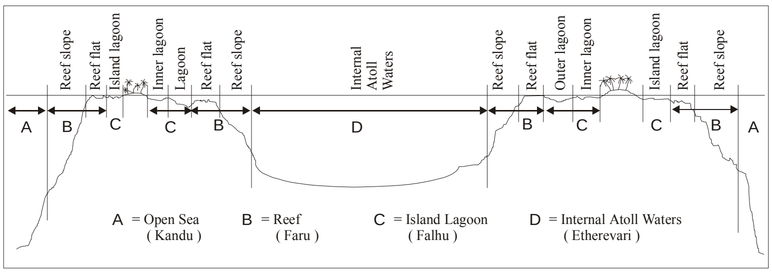


Figure 1: Cross section through a typical Maldivian Atoll (Adopted from BoBP, 1994)

Maldivian fishermen traditionally divide the marine environment into open sea or channels (*Kandu*) [A], reef (*Faru*) [B], lagoon (*Falhu*) [C] and atoll lagoon (*Etherevari*) [D] as shown in Figure 1. The sandy lagoon and the reef, for instance, being shallower and closer to the islands, are more accessible to the people than the atoll lagoon and open sea. As a result, the zones themselves are modified by activities such as harbour construction, land reclamation and coral and sand mining (BoBP, 1994). Tidal fluctuations and their consequences can be felt in the sandy lagoon and the shallow reef areas, whereas all these changes have negligible effects in the atoll lagoon and in the open sea.

2.2.2 Theories on the Formation of the Atolls of the Maldives

It is believed that the Maldives and other features of the Indian Ocean bottom were formed about 65 to 225 million years ago in the Mesozoic Era (Maniku, 1990). During the last 150 years, coral reef theory has been developed in relation to three well established geological events as controlling factors for atoll formation: *plate tectonics, glacial sea level changes and sub aerial erosion* (Stoddart, 1973).

Tectonic control relates to vertical movement of land relative to sea, of which subsidence is the key process for atoll formation. Glacial and sea level control refers to Pleistocene sea level changes and their effects on the formation of modern atolls (Daly, 1915). Sub-aerial erosion occurs when reefs emerge either by tectonic movements or by a drop in sea level (Purdy, 1974).

Despite the attempts by early authors to come up with a universal theory of coral reef growth, none were widely accepted and there is still much controversy as to how reefs have developed their shapes, sizes and features both in the modern environment and in ancient times. Darwin himself recognized the difficulty of synthesizing a universal reef theory (Naseer, 2003). Reefs of the Maldives in the Indian Ocean have been interpreted to display little evidence of subsidence during their formation (Purdy, 1981)

One theory is that the basin of the Indian Ocean was formed due to subsidence and oceanisation of the continental crust. "The compound atoll reefs of the Indian Ocean, of which Maldives forms the larger part, are believed to have been grown above the foundered continental (rather than oceanic) crustal segments" (Maniku, 1990). According to Gardiner (1902), the main Maldives plateau was formed by current and tidal erosion of the continental crust, and the atolls were subsequently formed by the growth of deep and later shoal-water organisms on this formation (Maniku, 1990).

2.2.3 Reefs

The Maldives archipelago contains 2,041 distinct coral reefs greater than 1 ha in area. Of these, 529 are located on the rims of the 16 atolls, five form the rims and lagoons of the five oceanic faros, and four form oceanic platform reefs, also rising from deep water but lacking a deep lagoon (Naseer et al., 2004). The remaining 1,503 reefs are lagoon patch reefs scattered throughout the lagoons of the 16 atolls. The total number of reefs within an atoll varies greatly, ranging from only seven in Seenu to 268 in Ari atoll (Naseer, 2003). The total surface area of the major reef structures of the Maldives is 21,372.72 km^2. Only 21.1% of this area (4,493.85 km^2) is actually occupied by distinct coral reefs (Naseer et al., 2004).

The characteristics of reefs and coral islands of the Maldives vary considerably from north to south. The atolls to the north are broad banks discontinuously fringed by reefs with small coral islands and with numerous patch reefs and faroes (derived from the Maldivian word "*faru*") in the lagoon. To the south the depth of atoll lagoons increases, faroes and patch reefs are rare in the lagoons, the continuity of the atoll rims is greater and a large part of the perimeter of the atolls is occupied by islands (Woodroffe, 1989).

The largest reefs of the system exist towards the eastern and southern regions of the Maldives. The reefs are also longer and more ribbon-like towards southern and south-eastern regions. Rim reefs appear to be more circular in atolls located on the northern regions and western side of the central region than the atolls found on southern regions and eastern side of the central region atolls. The southern and south eastern facing reefs receive more swell and high energy waves, and hence the rim reefs are more linear in shape than northern and western reefs, which do not receive swell waves (Naseer, 2003).

2.2.4 The Islands

The Maldives consist of 1190 coral and coral sand islands, of which 203 are inhabited and 87 are resort islands (MPND, 2006a). The islands are entirely built and sustained by the continuous ecological and physical processes in the coral reef ecosystem. The shapes of the islands depend largely upon wave action. Islands vary from small sandbanks with sparse vegetation in the centre to elongated strips and relatively circular islands with a large cover of vegetation.

Most of the islands vary in size from 0.001 to 2 km^2. Only 33 islands have a land area in excess of one square kilometre. According to Figure 2, more than 85% of the inhabited islands are less than 1 km^2 in size and only 3 inhabited islands have an area exceeding 4 km^2.

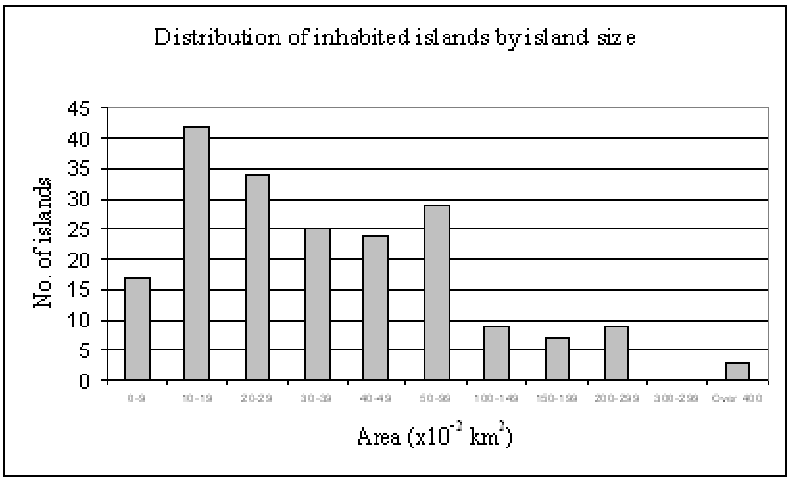


Figure 2: Distribution of inhabited islands by island size (source: data from MHAHE, 2001)

The official land area of Maldives is 298 km^2 or 300 km^2 (MPND, 2002), giving a population density of about 1000 persons per sq km in 2006. Hanson (1995) reported the vegetated land area as 185 km^2 based on the aerial photos which were taken in 1969, while the upper limit of land area, inclusive of beach and newly reclaimed land, was reported as 235 km^2 by Shaig (2006) who used Landsat 30 m resolution satellite images and Digital Globe (2.6-15 m resolution) for his estimate. Naseer (2003) reported the total island area of the Maldives to be 227.45 km^2 by interpretation of remotely sensed data collected by the Landsat-7 ETM+ earth-observing satellite sensor.

All islands of the Maldives are very low lying; more than 80% of the land area is less than 1 m above mean high tide level (MEEW, 2005). Combined with the small size of the islands, this means that accelerated sea level rise will have devastating effects on the islands and threatens the very existence of all the islands of Maldives.

2.3 Climate

The Maldives has a warm and humid tropical climate. The weather is dominated by two monsoon periods: the southwest monsoon from May to November, and the northeast monsoon from December to March. The southwest monsoon is the wetter of the two monsoons and is typically the period when most severe weather events occur. The annual relative humidity ranges from 73 to 85% (DM, 2006).

Although the Maldives is not located in a region of cyclones or other intense climatic events, historic evidence shows that the northern part of Maldives is affected by storms generated from cyclone activity (Maniku, 1990) & (Woodroffe, 1989).

2.3.1 Climate Trends

The following section gives the trends in the general climate for the Maldives.

2.3.2 Temperature Variations

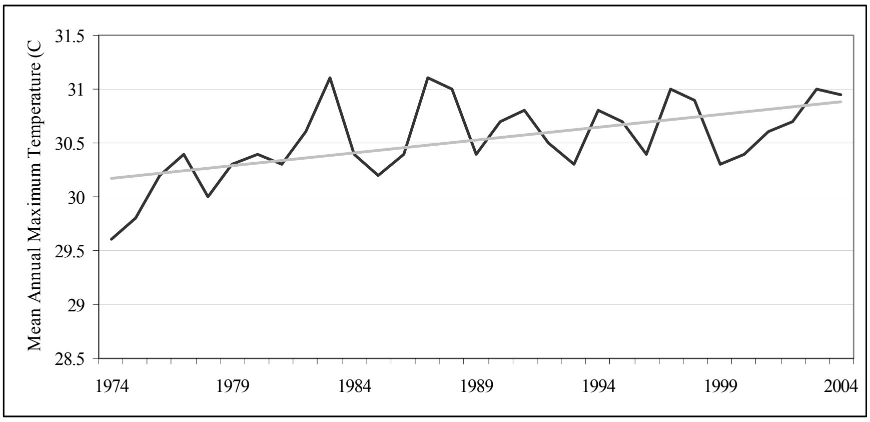


Figure 4: Mean Annual Maximum temperature for Malé (source: data from DM, 2006)

Daily temperatures vary little throughout the year with a mean annual temperature of 28 °C. Analysis of long-term annual maximum temperatures (1974 - 2004) show a rising trend (Figure 4). Annual maximum temperatures increase by 0.17 °C every 10 years, whilst annual minimum temperatures show an increase of 0.07 °C every 10 years (MHAHE, 2001).

2.3.3 Rainfall

Rainfall in Maldives varies from north to south with the amount of rainfall increasing towards the south. This difference in rainfall patterns is primarily due to the northeast monsoon period and April being much drier in the north than in the south (Edwards, 1989).

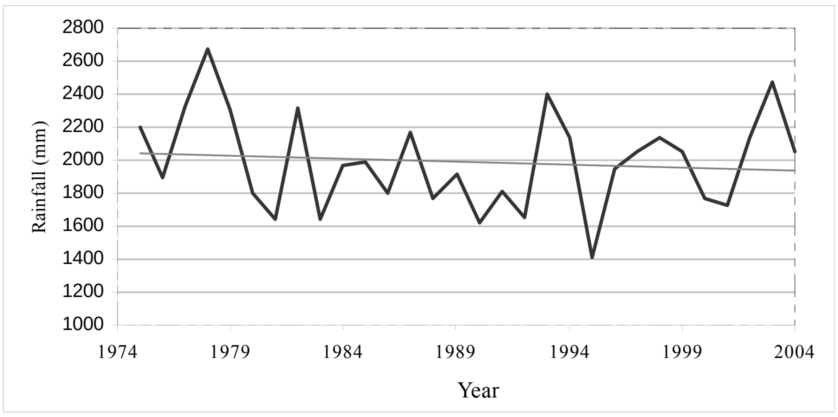


Figure 5: Annual variations of total rainfall for Malé (source: data from DM, 2005)

Analysis of long-term total annual rainfall data for Malé shows a decrease in rainfall. The trend shows a drop in 2.7 mm of rainfall every year which has been shown by the trend line in Figure 5.

2.3.4 Wind

The wind climate is dominated by winds from the west and northwest and winds from the northeast and east-northeast. Slightly stronger winds are associated with winds from the west typical of the southwest monsoon season. On average, wind speeds vary between 7-12 knots. The stormiest months are typically May, June and July during the early part of the southwest monsoon. Storms and squalls producing wind gusts of 50-60 knots have been recorded at Malé (DM, 2006). Figure 1 below, shows the variation in average seasonal wind speeds for Malé which is situated in the central region of the Maldives.

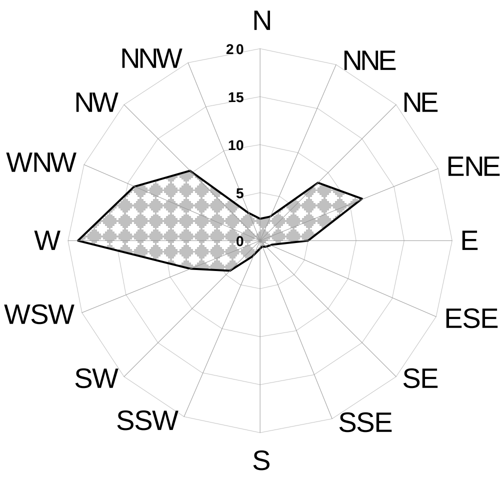


Figure 6 Variation in average seasonal wind speeds (knots) (1980 – 2003) (source: data from DM, 2006)

2.3.5 Rise in Sea Level

Based on observed data for Hulhulé, Hay (2006) reports the observed long term trend in relative sea level for Hulhulé is 1.7 mm/year (see Figure 7). This is towards the upper end of the estimated range of global sea-level rise over the past century, namely 1 to 2 mm/year, and above the central estimate of 1.5 mm/year. Thus the recent rise in relative sea-level observed at Hulhulé is consistent with global observations for the last 100 years, given that the rate of sea-level rise may well be accelerating due to global warming (Hay, 2006).

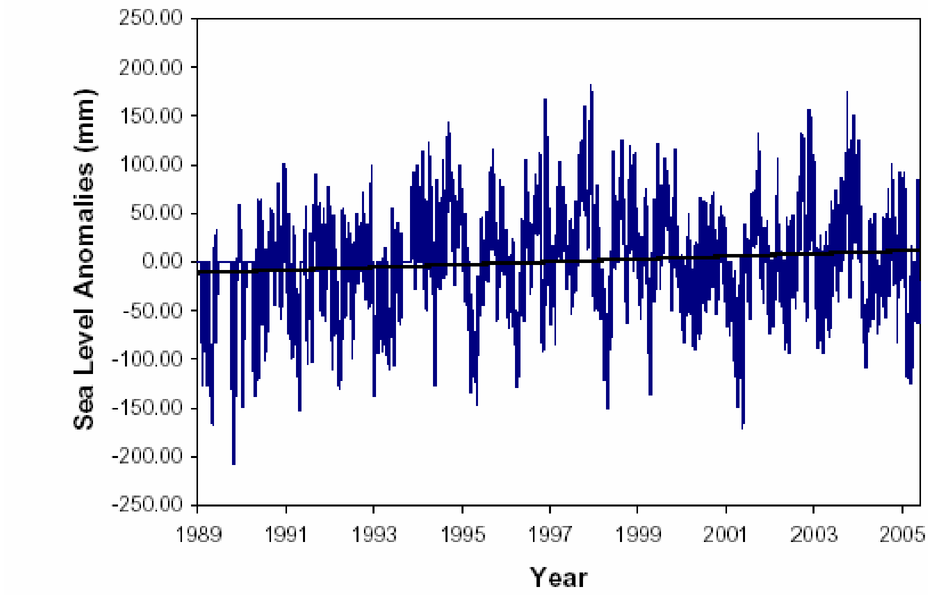


Figure 7: Daily mean values of sea level for Hulhule' relative to mean sea level (source: Hay, 2006)

2.4 Water Resources

The hydrogeology of the Maldives is that of typical coral islands. The Maldives has very little fresh water resource as 99 percent of the country is sea. Consequently, water remains one of Maldives' most scarce and precious resources. The main water resources of the Maldives comprise fresh groundwater that occurs in the porous coral sediments on many islands of the Maldives.

The population of Maldives has traditionally been dependent on groundwater from shallow wells dug in the ground. It has been estimated that currently 25% of the population depends on groundwater for drinking while the rest of the population uses rainwater and desalinated water for drinking, and groundwater for other purposes (MEEW, 2005)

The quality of groundwater varies seasonally and across the islands. The amount and temporal pattern of rainfall and the size and shape of an island determines the amount of fresh groundwater that accumulates. The fresh groundwater is found as a "freshwater lens" that comprises a freshwater zone underlain by a transition zone of a few meters thickness between the freshwater and underlying seawater. The top of each freshwater lens found in the islands of Maldives is generally 1.5 to 2 m below the land surface and changes continuously with the tide (see Figure 8).

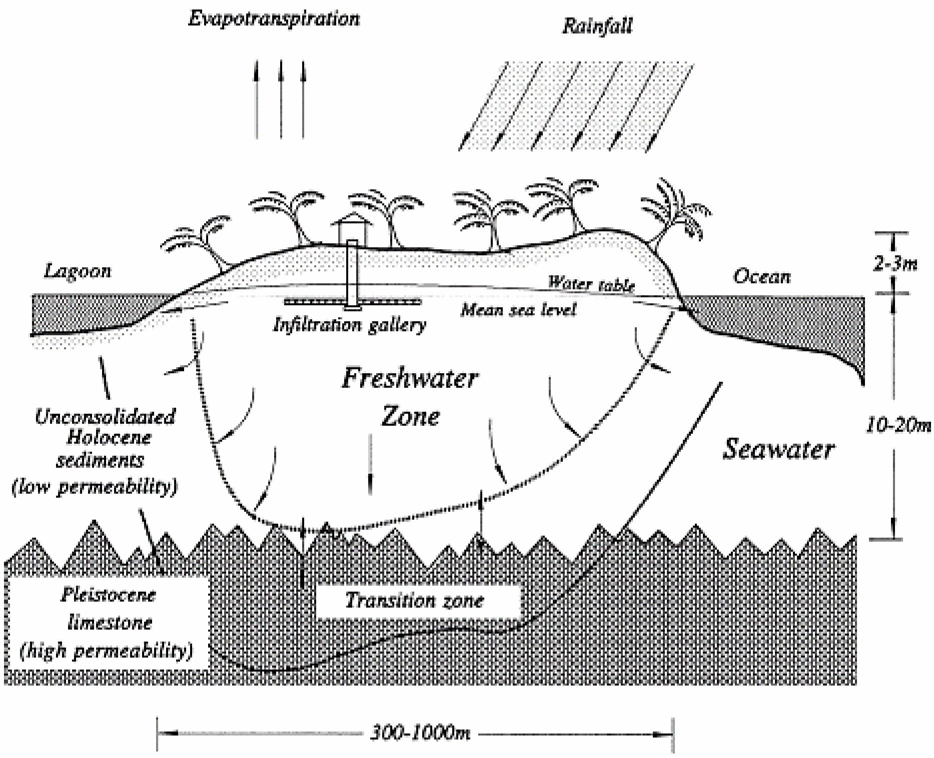


Figure 8: Cross-section of an island showing features of groundwater (source: Falkland, 2000)

Traditionally people depended on shallow wells to get access to the groundwater lens for drinking water. However, by 2004, 90 percent of the atoll households used rainwater as the principal source of drinking water while in Male', the whole population had access to piped desalinated water (MEEW, 2005). Following the Indian Ocean Tsunami 48 islands where groundwater is commonly utilized for washing and bathing, were contaminated so as to be unusable (WB et al., 2005). Three years after the Indian Ocean Tsunami, the groundwater of the Maldives has not recovered to its state in 2004. Following the dry period in March 2007, desalinated water was send to 90 islands across the archipelago.

In general the groundwater found in the islands has very low salinity. In many of the islands where studies have been done, it was found that bacterial content is very high. The source of this contamination is generally discharge and leakage from septic tanks.

For drinking purposes, rainwater is the traditional source for the Maldivians. Rainwater is harvested by individuals from roofs of houses during rain showers. The harvested rainwater is stored in tanks and other vessels. In almost all inhabited islands there are public rainwater storage facilities. Before harvesting rainwater, the roofs and storage vessels are allowed to be cleaned by the initial burst of rain.

Presently, more than 25% of the population depends on desalinated water for drinking and other uses. Desalinated water is used only in two inhabited islands, including Malé. Desalinated water has been available in Malé for more than a decade and all households in Malé now have access to piped desalinated water. However, rainwater is still harvested in Malé during the rainy season. In the resorts, mostly bottled water is used for drinking while desalinated water is used for other purposes (MHAHE, 2001).

2.5 Socio-economic Environment

2.5.1 Population

The population of the Maldives passed the 300,000 mark in July 2006 (MPND, 2006b). The population size among the atolls and the islands differs across the country. More than a third of the total population (104,403 persons) lives in the capital Male'. Of the atolls, Addu Atoll has the highest population at 17,922, while Vaavu Atoll has the lowest population at 1,614 (MPND, 2006b).

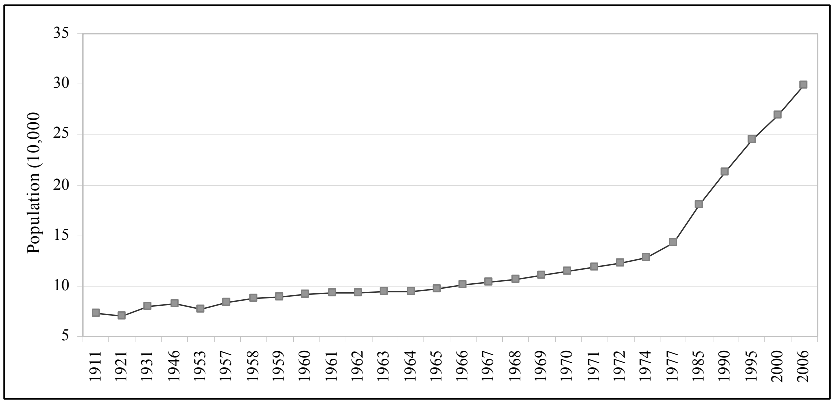


Figure 9: Population of the Maldives (1911 - 2006) (source: data from MPND, 2006c)

The distribution of the population in the Maldive islands is given in Figure 9. Apart from Male', there are only three islands that have a population greater than 5000. They are Hithadhoo (9407), Fuvahmulah (7642), and Kulhudhufushi (7206). In 2006, 57 islands had a population between 1000 and 5000 people, 60 islands had a population between 500 and 1000 people and 74 islands had a population of less than 500 people.

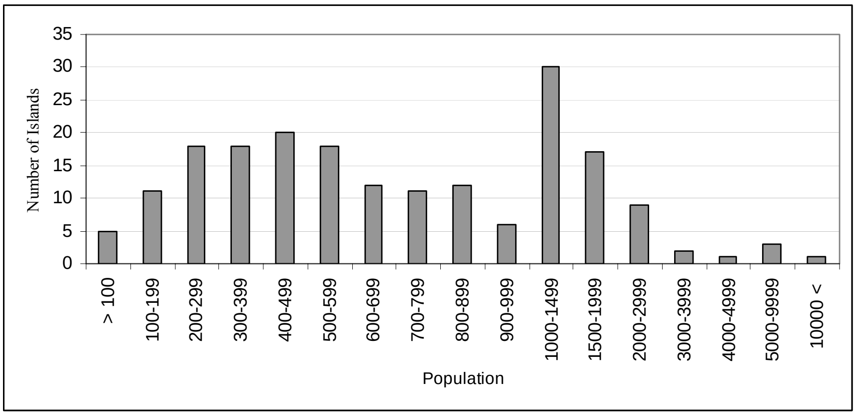


Figure 10: Spatial population distribution for Maldives (source: from MPND, 2006c)

The population density on some islands is very high. Nearly half the inhabited islands have population densities over 2,000 persons/km^2.

2.5.2 Economy

The Maldivian economy is heavily dependent on fisheries and tourism, which are the major sources of foreign exchange earnings and government revenue, and which together directly account for about 40 percent of the national Gross Domestic Product (GDP), while indirectly accounting for a much larger proportion of GDP (MMA, 2007). As seen in Figure 11, the GDP of the Maldives showed a negative growth of 4.6% between 2004 and 2005. This is attributed to the Indian Ocean Tsunami of December 2004 (WB et al., 2005). However due to the large amount of tsunami recovery and reconstruction work, which started in the Maldives, helped to recover from the direct damages to the economy.

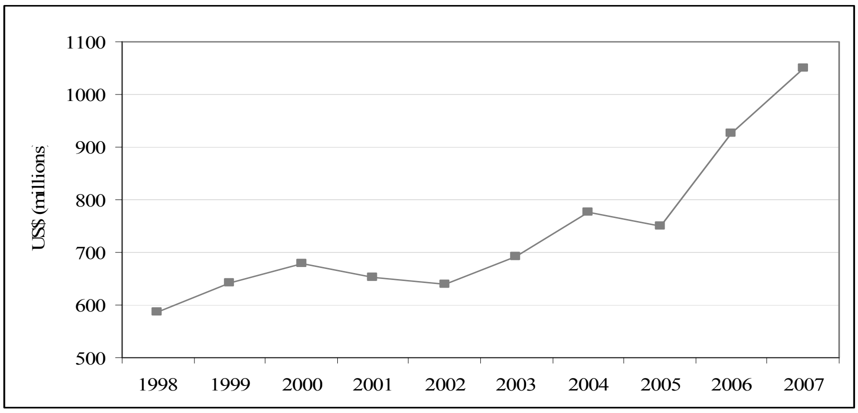


Figure 11: Gross Domestic Product (GDP) of the Maldives (1998 – 2007) (source: MMA, 2007)

2.6 Disasters and Episodic Events

"*As for my own country, the Maldives, a mean sea level rise of 2 metres would suffice to virtually submerge the entire country of 1,190 small islands, most of which barely rise over 2 metres above mean sea level. That would be the death of a nation. With a mere one metre rise also, a storm surge would be catastrophic, and possibly fatal to the nation.*" President Gayyoom, UNGA, New York, 1987

2.6.1 Extreme episodic events

The Maldives is not located on a cyclone belt hence does not experience the direct impact and devastation of cyclones, but historical records show several incidents of devastation caused by extreme weather due to the cyclone driven storms which passed few hundreds of kilometres away from the Maldives in the Indian Ocean. There have been several cases of islands even being abandoned due to damage caused by such storms. Historical records show that about 18 islands from the northern atolls have been abandoned after being devastated by storm events (Maniku, 1990).

Inundation of parts of islands, usually accompanied by high waves or heavy rainfall, is experienced by the islands of Maldives. These events occur mainly in the southern region and mostly from April to December which is the interim period between the northeast and the southwest monsoon. The island of Foammulah experienced 9 such events between 1977 and 1989 (Maniku, 1990).

According to Maniku (1990) storm events that are very localised to sometimes even one island (freak storms) occur in the Maldives. The resort island of Bolifushi was hit by such a freak storm in 2000. This storm lasted about 12 hours and caused US$ 1.2 million worth of damages (MHAHE, 2001).

The central part of Maldives experienced a strong tidal wave in April 1987. This caused extreme damage to the capital and the international airport (MEEW, 2005).

It is commonplace to see tide coming ashore in many islands throughout the country at high spring tide. There have been various incidents where trees, roads and houses, especially those nearer to the coastline, have been affected by floods during such tides.

2.6.2 Vulnerability to Natural Disasters

The islands of the Maldives are less prone to tropical cyclones and are only impacted in the northern part of the country by weak cyclones that formed in the southern part of the Bay of Bengal and the Arabian Sea. Since 1877, only 11 cyclones crossed the archipelago (Maniku, 1990). Most of the cyclones crossed Maldives north of 6.0° N and none of them crossed south of 2.7° N during the period. All the cyclones that affected Maldives were formed during the months of October to January except one, which formed in April (UNDP, 2006).

Map 4: Cyclonic Wind Hazard Map (source: UNDP, 2006)

The northern atolls have a greater risk of cyclonic winds and storm surges. This reduces gradually to very low hazard risk in the southern atolls (see Map 4). The maximum probable wind speed in Zone 5 is 96.8 knots (180 kilometers per hour) and the cyclonic storm category is a lower Category 3 on Suffir-Simpson scale. At this speed, high damage is expected from wind, rain and storm surge hazards (UNDP, 2006).

Figure 12 shows historical earthquakes around Maldives; and three events of magnitude above 7.0 struck the region which had their sources in the Indian Ocean. ((UNDP, 2006).

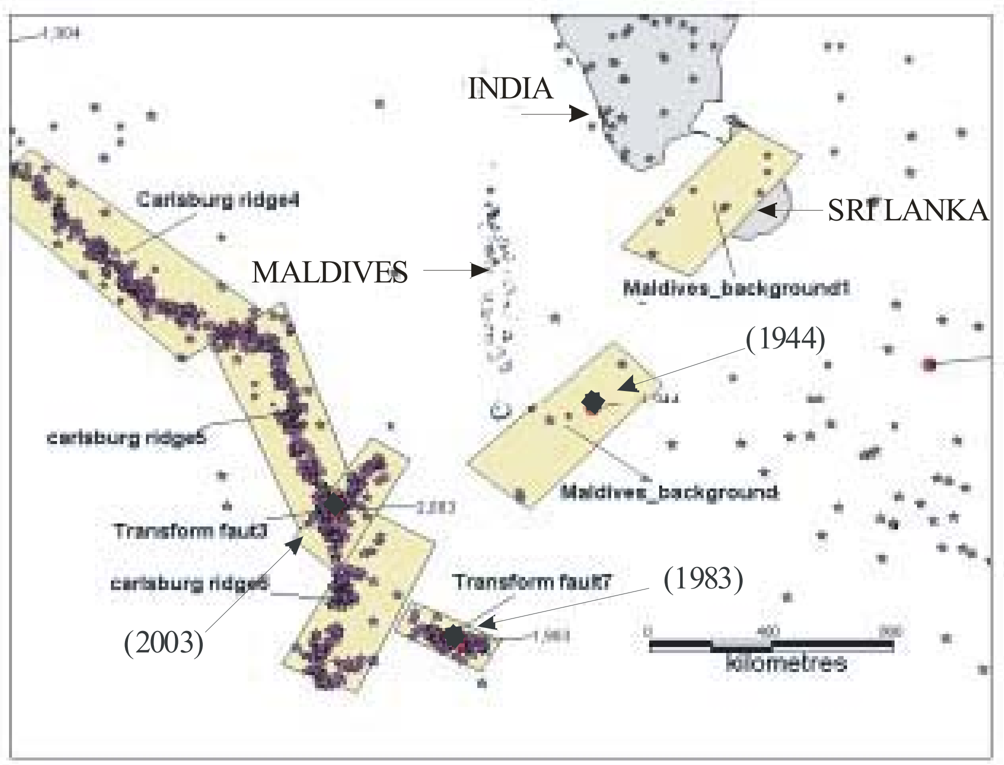


Figure 12: Earthquake Epicentres around Maldives (Source: UNDP, 2006)

UNDP (2006) identified that hazard risk from earthquake is low for the Maldives and considered as a disaster risk for only islands located in the south of the country. See Map 5.

Map 5: Earthquake Hazard Zone (source: UNDP, 2006)

Maldives faces tsunami threat largely from the east, and lower threat from the north and south. Islands along the eastern fringe of the atolls are more prone to tsunami hazard than those along the northern and southern fringes. Islands along the western fringe experience a relatively low tsunami hazard. Historically, Maldives has been affected by three earthquakes which had their sources in the Indian Ocean. Of the 85 tsunamis generated since 1816, 67 originated from the Sumatra Subduction zone in the east and 13 from the Makran Coast Zone in the north and Carlsburg Transform Fault Zone in the south. The probable maximum tsunami wave height is estimated at 4.5 metres.

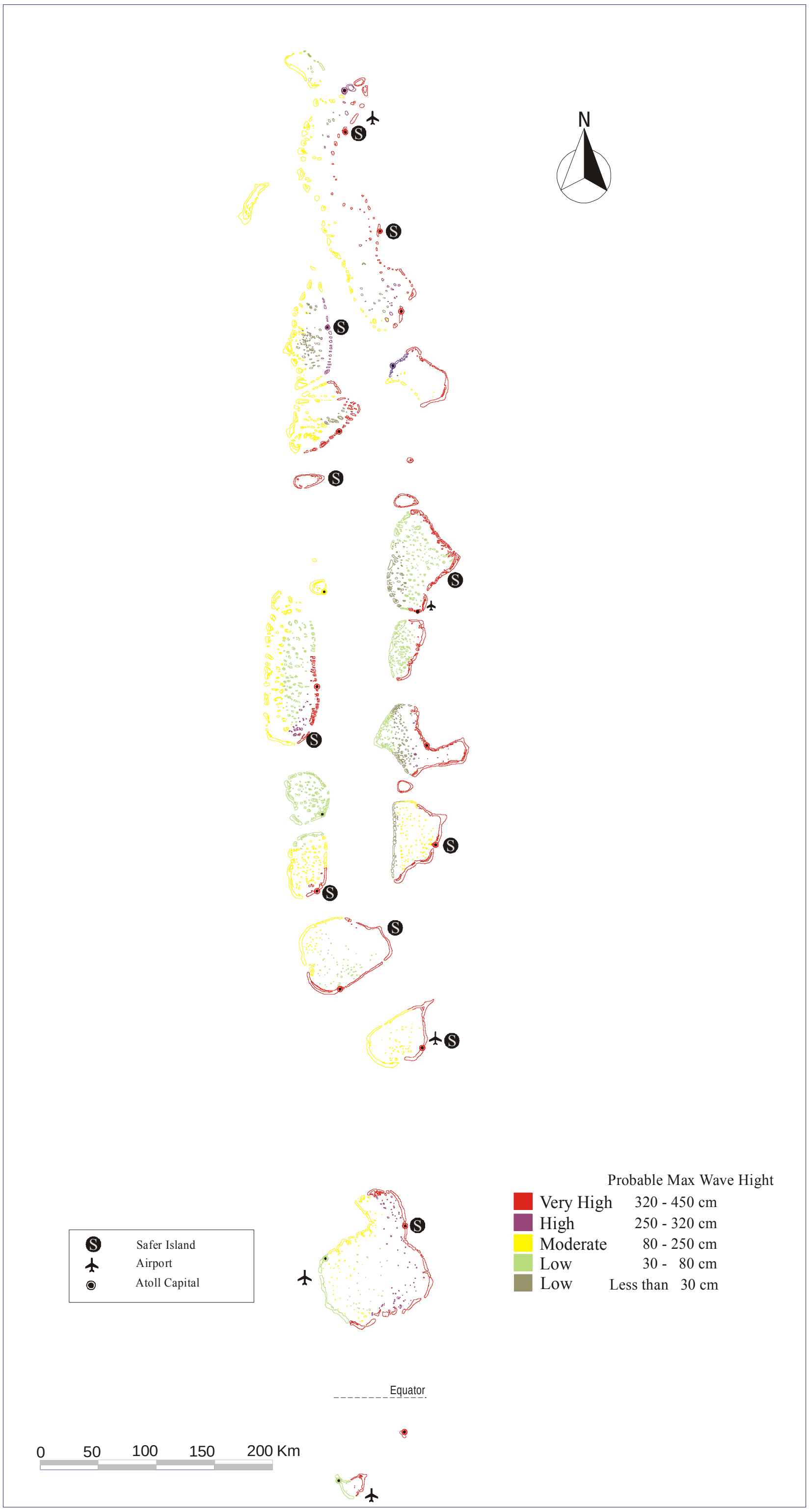


Figure 13: Tsunami Hazard Zones (adopted from UNDP, 2006)

3 Indian Ocean Tsunami

This chapter provides a brief background to the Indian Ocean Tsunami which was generated on 26 December 2004, and its impact on the natural, physical and social environment of the Maldives. The chapter will help to provide a setting to highlight the vulnerabilities of the islands of the Maldives to tsunami-like natural disasters.

3.1 Tsunami Characteristics

3.1.1 The Earthquake

The Sumatra-Andaman earthquake which triggered the deadly tsunami in the Indian Ocean occurred on December 26, 2004 at 00:58:53 Coordinated Universal Time (UTC). The epicentre of this relatively shallow (30 km deep) earthquake was located at 3.295 N 95.982 E (USGS, 2004). The 9.3 moment magnitude earthquake released 4.3 x 10^{18} J of energy or 475,000 kilotons (475 megatons) of TNT, or the equivalent of 23,000 Nagasaki bombs. The resulting sea floor movement displaced more than 30 km^3 of seawater (Bilham, 2005), This earthquake had the longest known earthquake rupture length of 1200 km from the epicentre to the north (Lay et al, 2005).

The Sumatra segment of the rupture zone, about 600 to 800 km north of the epicentre, experienced the largest and most rapid vertical slips, up to 20m during the first 230 seconds (Lay et al, 2005). Hence this length of the rupture zone is the main tsunami generation source region. The remaining northern part of the rupture zone did not experience rapid movement and the vertical slips were estimated to be less than 2 m, thereby, reducing the likelihood of generating massive tsunami waves (Lay et al, 2005).

3.1.2 Tectonic Settings

The great earthquake occurred at the seismic boundary formed by the convergence of the Indo-Australian plate and the Burma and Sunda subplates, which are part of the Eurasian plate. The Indo-Australian plate, which is believed to be segmented into the Indian and Australian plates, moves generally northward at 40 to 50 mm per year, colliding with the Eurasian plate. The Maldives lies on the centre of the Indian plate. The oceanic crust of the Indo-Australian plate gets subducted beneath the Eurasian plate forming the subduction zone known as the Sunda Trench which extends over 5600 km between the Myanmar and Timor (Newcomb and McCann, 1987).

3.1.3 The Tsunami

The resulting tsunami that was generated at 00:58:53 UTC propagated across the Indian Ocean attaining a maximum speed of nearly 900 km per hour. It reached the east coast of Africa in less than 10 hours after generation. Figure 14 shows the computed tsunami wave travelling across the Indian Ocean basin, using numerical modelling.

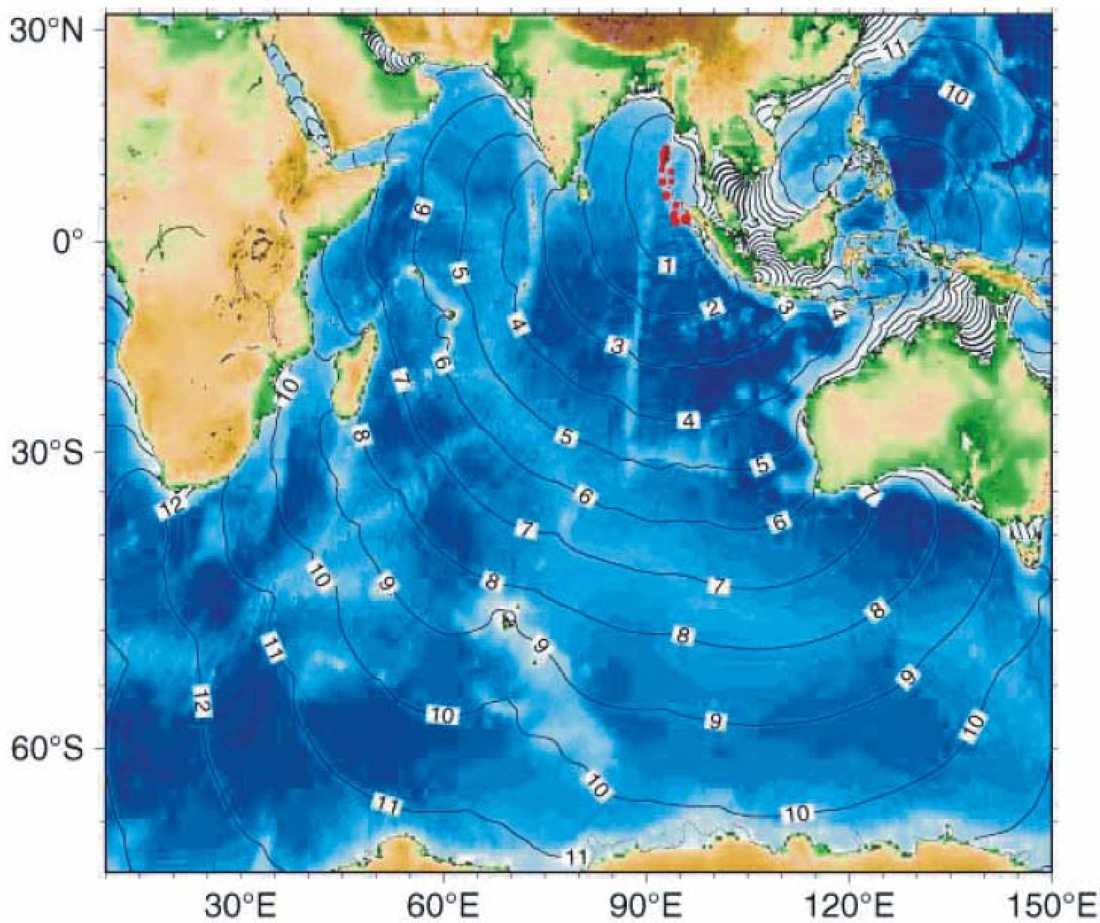


Figure 14: Computed tsunami travel time in the Indian Ocean (NOAA et al., 2005)

The first waves struck the Maldives at 04:20 UTC (09:20 A.M. local time), less than four hours after generation. The leading wave front of the tsunami arrived almost broadside to the Maldives plateau, slamming into eastern shorelines almost simultaneously in all parts of the country. This is verified by tide data from the three tide stations at Haa Dhaalu Hanimaadhoo (located in the northern region) , Kaafu Male (located in the central region) and Seenu Gan (located in the southern region)

Figure 14. The arrival times for the three tide stations differ only by fifteen minutes. Tidal data indicated wave heights of 1.83 m at Hanimaadhoo, 1.42 m at Male' and 0.79 m at Gan, but these heights do not correspond to the actual tsunami height at the respective shorelines and the resulting run-up at these locations because according to Kilonsky (2005), these tide data have been filtered both mechanically and over time.

The actual run-up measurements for all of these three locations are higher than the values recorded by the tide gauges. The wave periods for these 3 tide stations were estimated as 42 minutes for Hanimaadhoo, 36 minutes for Male' and 40 minutes for Gan. This was done by determining the elapsed time between the first two peaks. Therefore the average period of the leading tsunami wave fronts was approximately 39 minutes (Ali, 2005).

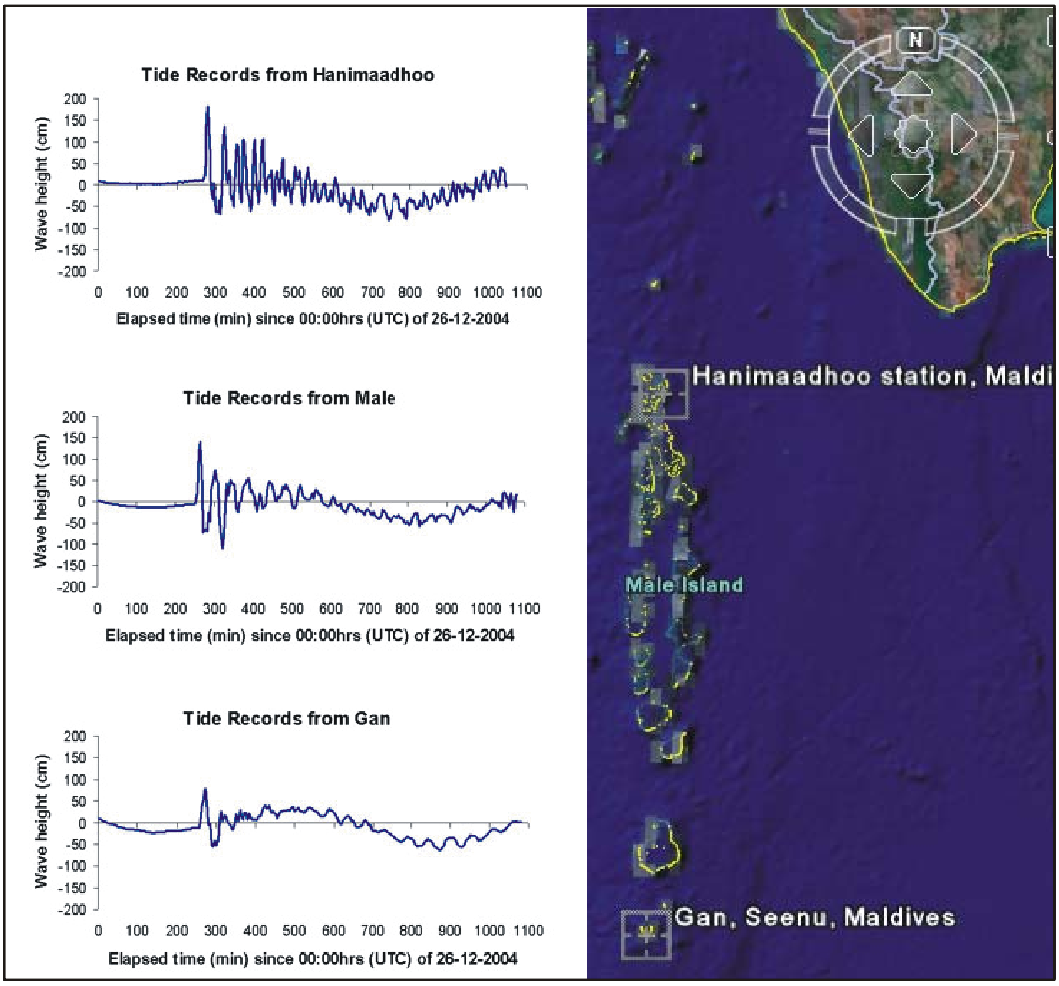


Figure 15: Tide records for December 26 2004 at Hanimaadhoo, Male' and Gan (source: Kilonsky, 2007)

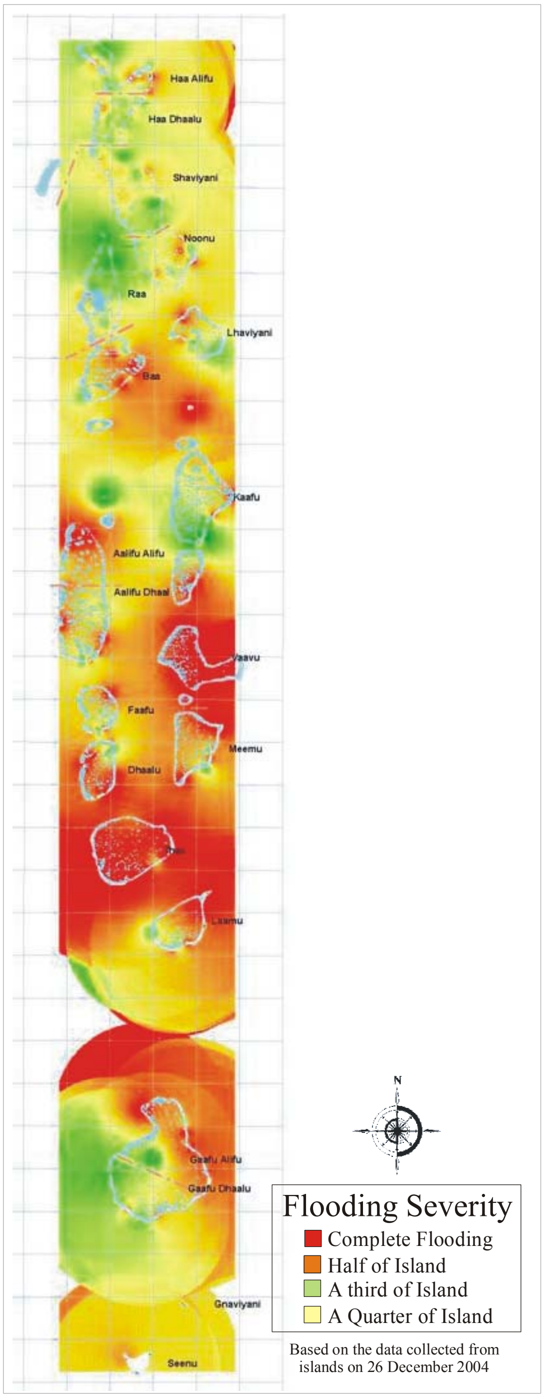
All three graphs, on Figure 15, show an initial peak followed by a depression indicating the first wave of the tsunami was a leading positive wave, i.e. a wave crest reached the shoreline first, followed by a trough. Also the first peak is the highest in all three cases. This is in consistent with eyewitness reports gathered from islanders, who reported an initial wave which surged in like a rapidly rising tide followed by a rapid draw-down (UNEP, 2005). These reports also indicated that the first wave was the largest in all the impacted islands, with consecutive waves getting smaller. Most islands reported three large surges, with the draw-down of the water level following each surge. The draw-down also got smaller compared to the preceding surge. Although most islands reported similar sequence of events, there were some variations among some islands (UNEP, 2005). As one would expect, the first wave hit the majority of the islands from the eastern end of the island, but there were reports from several islands, where the second and sometimes the third wave surged in from the western side. This has been suggested water level change at backwash phase was large than that at up-rush phase due to topography difference from eastern and western side of the island (JSCE, 2005).

Most of the islands throughout the country reported waves surging in like a rapid flood tide. Only a few reported bores surging into the islands. Run-up ranging from one to over four meters was measured around the country.

3.2 Impact on the Natural Environment

3.2.1 Coastal Environment

Although the country is made up of nearly 1200 islands, tsunami impact data was collected from the 204 islands that were inhabited prior to the tsunami and from a few tourist resort islands. Of these 204 islands, 14 islands were completely destroyed and the inhabitants evacuated. A further 56 islands suffered severe to substantial damage. Only 9 islands escaped any form of inundation or damage. Map 6 shows the level of damage at atoll level using the damage level information from individual islands in each atoll.



Map 6 Flood Severity (data source: National Disaster Management Centre)

The analysis of the island level data which was collected by the National Disaster Management Centre following the Indian Ocean Tsunami showed that the tsunami had an impact on the beaches of 135 inhabited islands, 100 of those were located on eastern side of the country. The tsunami impact on the beach also depended upon its location with respect to where the island was located in the atoll. 29 islands which were impacted were located inside the atoll, 80 islands were located on eastern rim of the atoll and 26 impacted islands were on the western rim of the atoll.

Beach erosion on these islands appeared to be widespread and characterized by the formation of erosional scarps typically 0.3 to 0.5 m high (UNEP, 2005). Material was generally deposited landward of the eastern beach ridge (especially in mangroves) and within western lagoon areas.

The study conducted by UNEP (2005) found that the tsunami impacts varied from complete island over-wash to inundation around island margins. Natural shorelines and land surfaces, either on uninhabited islands or natural areas of inhabited islands, suffered much less damage than developed areas. Changes to coastal morphology tended to be greatest among those islands located close to the eastern reef rim facing the direction of the tsunami's approach (see Map 6 Flood Severity (data source: National Disaster Management Centre)

3.2.2 Coastal vegetation and forests

Much of the tsunami's force was dissipated in areas where the island beach was fronted by a dense littoral hedge of native shrubs such as *magoo* (Scaevola sericea Vahl) and *kuredhi* (Pemphis acidula J.R. Forst & G. Forst.). UNEP Post Tsunami Environment Assessment (2005) found that apart from accumulations of waste on the coastal vegetation, there was little evidence of damage to the green belt of the island. Because native species are all salt-tolerant, there was no widespread mortality in natural coastal forests as a consequence of salinisation caused by the flooding from tsunami.

It was found that, in general, natural shorelines and land surfaces were impacted less during the tsunami than the developed features. Tsunami impacts were greatest where villages or cultivated fields directly abutted the sea with little or no coastal protection. Wherever a fringe of natural coastal forest or mangroves had been left untouched there was a marked reduction in erosion and destruction of buildings. Natural vegetation withstood the impact, reduced flow velocities and filtered large quantities of debris from the waves. Scrub vegetation appears to have been more effective as a natural defense than mature trees (Raman, 2005). Groves of coconut trees and banana plantations with little undergrowth appeared to have provided little protection and in some cases may have increased turbulence and scour (UNEP, 2005).

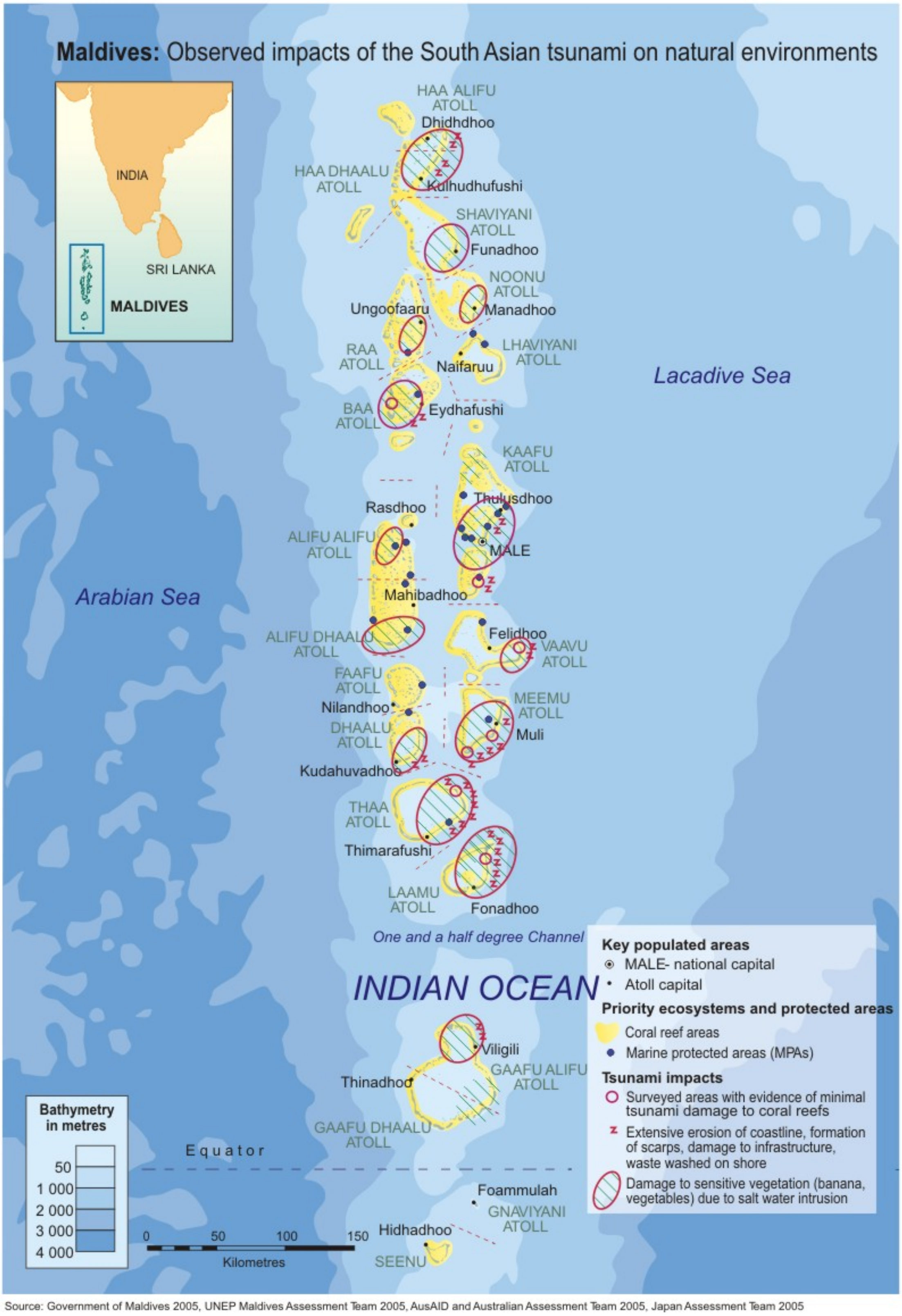


Figure 16: Tsunami Impact on Natural Environment of the Maldives (source : UNEP,2005)

3.2.3 Groundwater

Groundwater aquifers in the Maldives islands are very shallow between 1 and 1.5 metres below the soil surface; see section on Groundwater in chapter 2.4. According to the State of the Environment Report (2005), only 39 inhabited islands had groundwater that was suitable for drinking before the tsunami. The quality of groundwater supplies in 36 islands have been compromised due to saline and sewage contamination following the tsunami (WB et al., 2005).

3.2.4 Coral Reef

A team of Australian marine scientists assisted in the assessment of damage to the coral reefs of the Maldives following December 2004 tsunami. They found that the tsunami had less impact on the reef flats, islands and beaches than was expected.

The tsunami approached islands from the outside of the atoll, including on the western side. Reef flats on the outside of atolls were minimally impacted. The outside of atolls (whether on the east or west) were generally least affected. It was observed that variable damage was sustained to reefs inside of the atoll rim. Areas of reef sheltered behind islands (on the eastern side of atolls) generally experienced least damage. Areas of reef not sheltered by islands typically had more damage, although most reef areas were still a little affected. Reefs in the centers of atolls generally showed little damage from the tsunami (MRC et al., 2005)

3.3 Impact on the Social Environment

The tsunami left a significant signature on the social environment of the Maldives. The direct impact included killing 82 people and leaving 26 people missing. More than 15,000 people were internally displaced when tsunami wave impacted the infrastructure on 49 islands.

Indirect impact caused by the tsunami included generation of approximately 290,000 cubic meters of demolition waste. UNEP (2005) found that the waste was diverse in nature, comprising hazardous waste (oil, asbestos, batteries, etc.), vegetation, soil, sediment, municipal waste from dump sites, healthcare waste, demolition waste (concrete, brick, timber, etc.) from destroyed buildings, oil spilled from generators, leakage from septic tanks and wastes generated by relief operations.

3.4 Built Environment

The tsunami destroyed much of the country's physical asset base including homes and entire settlements, public service utilities such as hospitals, clinics and schools, transport and communications infrastructure, private businesses and livelihoods (MPND, 2005a). Figure 17 shows the number of houses which were completely destroyed at islands which were impacted at various level by the tsunami.

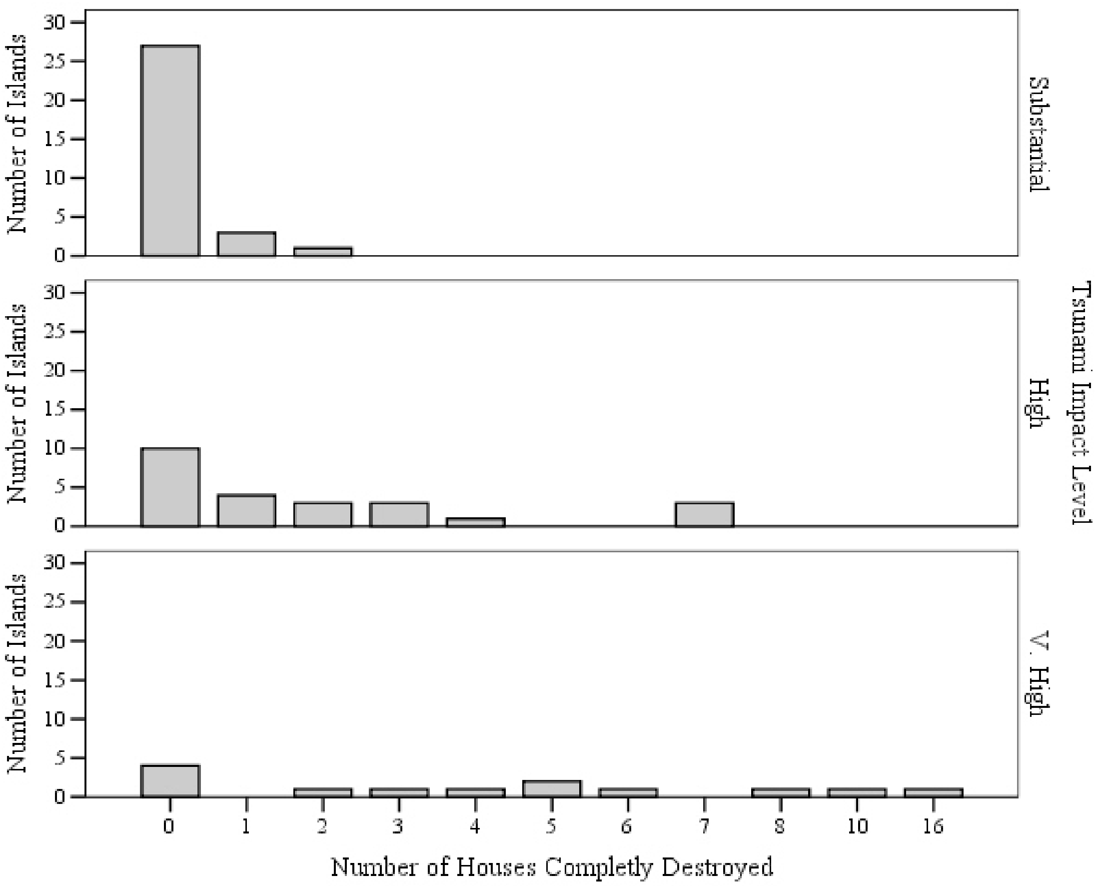


Figure 17: Houses completely destroyed by the Tsunami (data source: MPND, 2005b)

3.5 Impact on the Economic Environment

Total monetary damages caused by the tsunami were estimated to range from \$345 million dollars to \$385 million which was close to 55% of GDP. About \$244 million of this is direct damage and the rest is indirect. The largest source of direct damages is the housing sector with losses close to \$55 million and the largest source of indirect damage is the tourism sector due to a sharp drop in tourist arrivals (WB et al., 2005).

3.5.1 Impact on Tourism Sector

Tourism is the most important sector of the Maldives economy and has been the driving force behind the country's recent economic expansion. Since 1978, the numbers of resorts have more than quintupled, from 17 to 87. The impact from the tsunami was significant for both the private and public sectors. Three foreign tourists died, and 19 resorts were initially closed. Approximately, 1,200 hotel beds sustained serious damage and remained closed for 2005. In the two months following the tsunami, tourist arrivals declined markedly. Scheduled and charter flights were reduced and a number of resorts cut their staff sizes. Occupancy rates fell to 40% from 95% of the 17,476 registered hotel beds in the tourism sector.

Direct damage to the tourism infrastructure and other related businesses was estimated at over $100 million. Approximately 30% of beds were put out of service due to the impact of the tsunami (WB et al., 2005).

3.5.2 Fisheries Sector

Fishing is a crucially important livelihood in Maldives and represents a major source of protein for Maldivians. The tsunami caused loss or destruction of 120 fishing vessels, partial damage to 50 vessels, 5 reef fishing boats lost equipment and 16 ocean cages were lost, 374 fish processors lost equipment, while 8 boatsheds and 2 fishery institutes were damaged (WB et al., 2005).

4 Natural Disaster Management

When the Indian Ocean Tsunami washed out the livelihoods of thousands of coastal communities in a matter of minutes, many people of the impacted region wondered how it happened. The Urban Planners never thought a tsunami could sweep through the archipelago of the Maldives. For example, development planners had not allocated adequate resources to develop alternative water resources as groundwater which has been used by the local people for over four thousand years was sound to be ‘abundant’ in the country. The tsunami became a natural disaster impacting lives of the people, destroying livelihoods, sweeping away the development of many decades and impacting sustainable development initiatives.

This chapter will give an overview of the integrated disaster management models that are being globally used in the context of disaster mitigation. This chapter also provides details of the Safer Community approaches that are being used in New Zealand and UK. The Safer Island Development Programme of the Maldives is also described in this chapter.

4.1 Hazard and Disasters

4.1.1 Environmental Hazards (Cause)

Environmental hazards are potential threats posed to humans or nature by events originating in, or transmitted by the natural or built environment. These threats can be rated according to natural processes (natural hazards) or human actions (environmental impacts) and the extent to which hazards are voluntary or involuntary (Smith, 2004). Figure 18 presents a spectrum of hazards which can be classified as natural and human induced, intense and diffuse, involuntary and voluntary. A hazard with a high level of human causation like air pollution is voluntary in terms of its acceptance and more diffuse in terms of its disaster impact.

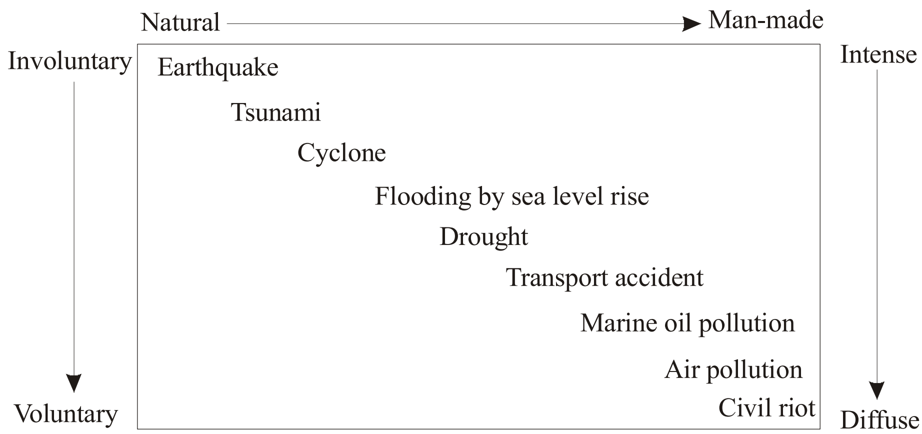


Figure 18: Spectrum of Environmental Hazards (adopted from Smith, 2004)

4.1.2 Risk (likely Consequence)

Risk is the actual exposure of something of human value to a hazard and is often regarded as the product of probability and loss. The probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) results from interactions between natural or human induced hazards and vulnerable conditions (U.N, 2005). Conventionally risk is expressed by the equation

$$\text{Risk} = \text{Probablility x Loss}$$

4.1.3 Disasters (Actual Consequence)

Disasters are social phenomena that occur when a community suffers exceptional, non routine levels of disturbance and loss. When a large number of people are killed, injured or affected in some way, the event is referred to as a disaster (Smith, 2004). A disaster is an actual happening, rather than a potential threat.

4.2 Integrated Disaster Management

Disasters have impact on sustainable development. Following the Indian Ocean Tsunami, the Hyogo Declaration (2005) which was adopted at the World Conference on Disaster Reduction underlined the link between disasters and their potential hindrance to the activities of sustainable development. The declaration recognised the need to continue to develop an understanding of, and to address, socio-economic activities that exacerbate the vulnerability of societies to natural disasters, to build and further strengthen community capacity to cope with disaster risks and to enhance resilience against hazards associated with disasters.

Smith (2004) noted (as in Figure 19) that environmental hazards exist at the interface between the extreme events and technological failures, where hazards and human response to them can influence sustainable development. This was seen on 26 December when the tsunami (extreme event) approached the islands of the Maldives, the infrastructure on the islands (not properly designed and built and, hence, technological failure) became an environmental hazard to the communities living on the islands. The response from the communities as a reaction to the tsunami caused a huge impact on the sustainable development agenda of the Maldives.

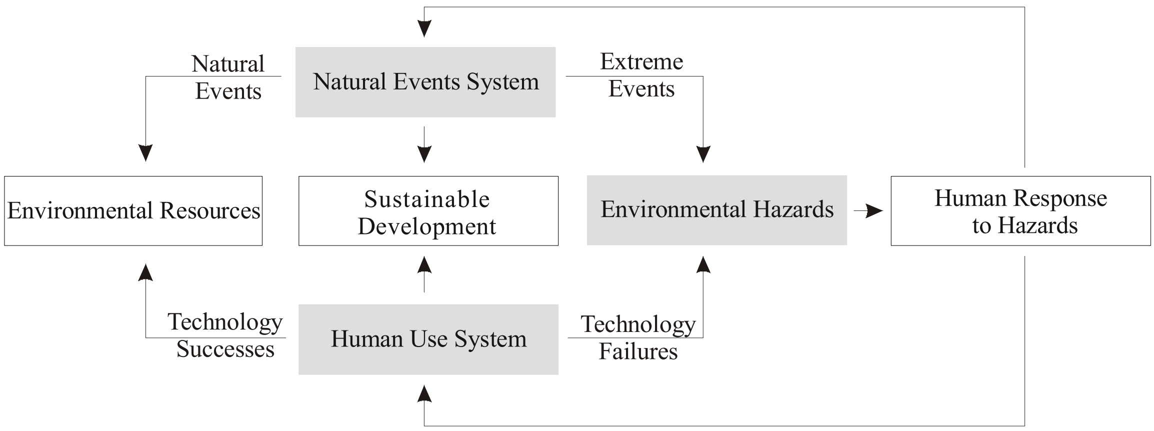


Figure 19; Management of Disaster is important for Sustainable Development (Source: Smith, 2004)

4.3 Assessment of Critical Hazards and Disasters

4.3.1 Vulnerability of Small Islands to Impacts of Tsunami

A number of studies have been carried out to assess the environmental damage to the islands of the Maldives caused by the tsunami. UNEP (2005) reported that the tsunami worsened chronic shoreline erosion problems in the islands while JSCE (2005) noted that properly built hard structures such as the sea wall around Malé played an important role in protecting the island from the impact of the tsunami. UNDP (2006) describes the disaster risk scenario for the Maldives as moderate owing to low probability of hazard occurrence but high vulnerability due to the geographical, topographical and socio-economic factors in the islands. Earthquake and tsunami hazard to the Maldives is largely from the northern Sumatra and Makron region. The hazard from cyclonic winds and storm surges is greater in the northern and southern atolls (UNDP, 2006). MEEW (2006) considered extreme rainfall, drought, high sea level and gale winds as the potential sources of climate-related risks for the Maldives. These have led to the realisation of the need to consider mitigation and adaptation measures for minimising the risks of hazards and disasters in medium and long-term development planning.

4.3.1.1 Geophysical Characteristics of the Islands

Recent disasters and extreme events show that the levels of impacts on to the islands from such events have a spatial distribution; an island's vulnerability depends on its geographic location and geomorphology. Geographic features include location of the island, reef of the island, spatial distributions of the reefs and islands which shadow or obstruct the approaching wave and the source of the tsunami, which controls the characteristics of the tsunami such as direction and magnitude. Geomorphological factors include width and orientation of the protective island reef, shape (Yeh et al., 1994), size of the island (Kench et al., 2006) and height of the island's bund, which is the physical barrier protecting the island from overtopping by waves (UNEP, 2005).

4.3.2 Analytical and Assessment Tools and Methods

A number of techniques and methods exist for undertaking vulnerability assessments for hazards and disasters. Buckle (2001) outlines Assessment Matrix, Brainstorming, Cost Benefit Analysis, Delphi Techniques, Environmental Impact Assessment, Focus groups and workshops, Mapping, Profiling, Scanning, and Scoping, Social Impact Assessment, Surveys, Questionnaires and Interviews, Trend Extrapolation, Cross Impact Analysis and Scenario Analysis and Planning as the most commonly used vulnerability assessment methods in the disaster management. The type of assessment tools and methods chosen depends on the type of hazards.

4.3.3 Tsunami vulnerability assessment

Models have been developed to aid in the process of understanding, assessing and mapping hazard, risk and vulnerability and these models may be conceptual, practical, or analytical. Model data outputs are often used to determine land use zoning and planning, emergency response actions, disaster planning and insurance premiums (Dominey-Howes et al., 2007).

4.3.4 Papathoma Tsunami Vulnerability Assessment Model

In recent years, efforts have been made using Geographic Information System (GIS) frameworks to develop vulnerability assessment models for many types of natural hazards. One such model, the ‘‘Papathoma Tsunami Vulnerability Assessment Model’’ (or PTVAM model for short; Papathoma et. al. (2003) was developed to investigate the vulnerability of coastal areas to tsunami. Dominey-Howes et. al. (2007) validated the PTVAM using the results from post tsunami surveys in the Maldives following the 2004 Indian Ocean tsunami to ‘evaluate’ the appropriateness of the PTVAM attributes to understanding spatial and temporal vulnerability to tsunami damage and loss.

The PTVAM is a dynamic model that incorporates multiple parameters or ‘attributes’ that are known to influence vulnerability to tsunami loss and damage. The model is dynamic in that the attribute data contained within the primary database may be modified and updated allowing investigation of vulnerability both spatially and temporally. The PTVAM is organised and presented within a GIS framework thus allowing rapid data entry and visualisation of changing vulnerability (through the production of new maps).

Based on an analysis of multiple post-tsunami field surveys, Papathoma (2003) identified a suite of ‘attributes’ (parameters) that are reported to affect the degree of damage from, or protection to, tsunami flooding for individual buildings and structures. These attributes were then classified into ‘major classes or groups’ (e.g. built environment, sociological data, economic data and environmental/physical data) and variations (values) in the degree or range of these attributes were identified together with a vulnerability descriptor for each attribute.

4.4 *Integration of Hazard and Disasters Management in National Sustainable Development Planning*

4.4.1 Indicators to assess the Impact of Disasters

Understanding the economic and social consequences of living in a coastal environment is fundamental. Such an understanding usually predates management actions to control or mitigate the consequences of these events. It is also often required to stimulate necessary investment in oceanographic prediction and control devices and associated modelling and analysis. It is also relevant for an assessment of the consequences of human-induced coastal habitat alteration that may exacerbate the impact of natural weather events.

The International Oceanographic Commission (IOC) began in 2005 to develop a common set of indicators to assess and report on the progress and results of integrated coastal and ocean management programs. One such indicator is weather and disaster, which provides information on the extent to which human lives and human property are affected by natural weather and disaster events (IOC, 2005).

IOC's initiative is a general approach to take into account the impact of weather and disasters on the coastal environment for the management of the coastal areas of the countries. A more specific set of indicators was developed by Dominey-Howes et al. (2007) to investigate the vulnerability of coastal areas to tsunami.

Dominey-Howes et al. (2007) presented a reviewed indicator set (see Table 1) for undertaking tsunami vulnerability assessment for coastal communities after validating the PTVAM model using the data collected in the Maldives following the Indian Ocean Tsunami in December 2004.

Major class	Attribute	Attribute Description	Vulnerability description
The Built Environment	Number of stories in each building	Only one floor	High
		more than one floor	low
	Description of ground floor	open plan with movable objects	High
		Open plan with big glass windows without movable objects	Moderate
		none of above	low
	Building surroundings	No barrier	V. High
		Low/narrow earth embankment	High
		Low/narrow concrete wall	Moderate
		High concrete wall	low
	Building material, age & design	Buildings of fieldstone, unreinforeced, crumbling and deserted	High
		Ordinary masonry brink buildings, cement mortar, no reinforcement	Moderate
		Precast concrete skeleton, reinforced concrete	low
	Shape and Orientation of Builldings	Square or oblong shaped structure	High
		non-cubic shaped building	low
		walls parallet to shore line	High
		Corners of building facing the shoreline	low
	Building use	Residential	-
		Services (schools, hospitals, power, ets)	-
		Commericial	-
Population data	Population density	Population density during night	High or Low
		Population density during day	High or Low
	Number of people per building	Many	High
		Few	low
Infrastructural frameworks / awareness	Government relief structures	Government provides full relief/compensation	low
		Government provides some relief/compensation	Moderate
		Government provides no relief/compensation	High
	Insurance policy	Household/business has tsunami insurance cover	low
		Household/business does not have tsuanmi insurace cover	High
	Household/business awareness and pre-planning	Resident/owner aware of tsunami risk and has acted accordingly	low
		Resident/owner aware of tsunami risk but has not acted	High
		Resident/owner not aware of tsunami risk and not able to act	High
Defensive structures	Physical or man-made barriers/sea defence	No protective barriers	High
		Soil embankment (offers moderate protection against flooding)	Moderate
		Concrete stone wall (offers high protection against flooding)	low
Environmental data	Natural environment	Wide intertidal zone	low
		Intermediate intertidal zone	Moderate
		Narrow intertidal zone	High
	Land cover (vegetation)	No vegetation cover	High
		Scrub and low vegetation	Moderate
		Trees and dense scrub	low

Table 1 Indicators for Assessing Tsunami Vulnerability (Source: Dominey-Howes et. al., 2007)

4.4.2 Sustainable Development Planning

In order to reduce the social, economic and environmental vulnerability of the widely dispersed population of the Maldives, the Government of Maldives initiated a programme for providing incentives for voluntary migration to larger islands in 2002. The long term objective is to reduce the number of inhabited islands and consolidate the population in smaller groups of settlements across an identified number of islands. The country will be divided into 5 regions comprising (a) regional focus islands, (b) atoll focus islands and (c) primary islands. However, the recent tsunami disaster has shown that the strategy of consolidating the population is in itself not a sufficient framework for sustainable development. It has become clear that not all islands are ecologically safe, highlighting the importance of integrating safety considerations in the widest sense, in planning the development of low lying islands. Hence it has become necessary to develop a concept of Safe Islands that could be developed as part of the overall atoll development strategy.

4.5 Integration Models

New trends in disaster risk management have gradually emerged in the past decade by shifting the focus from hazard assessment to vulnerability assessment emphasis on ‘‘disasters’’ rather than ‘‘hazards’’ both in substance and in terminology, from top down approaches to bottom-up approaches focusing on increasing the resilience of the communities and moving from responding to disasters to mitigating disasters at first place. Weichselgartner et al (2002) and White et al. (2001) marked improvement in our understanding of core issues at the heart of these concepts (Alexander, 2000; Wisner et al., 2004). Models have been developed to aid in the process of understanding, assessing and mapping hazard, risk and vulnerability (Dominey-Howes et al., 2007).

4.5.1 Reducing vulnerability and increasing resilience

The key focus of disaster management is to reduce the vulnerability of the communities exposed to hazards and risks and to help them to enhance their resilience. The Hyogo Framework for Action 2005-2015: The Hyogo Declaration (2005) called upon countries to develop strategies to reduce their vulnerabilities by means of integrated environmental and natural resource management approaches that incorporate disaster risk reduction, including structural and non-structural measures and enhance the resilience of the community at the grass root level.

4.5.1.1 Safer Sustainable Communities

Efforts have been made to develop safer and sustainable communities in all corners of the globe from developed to developing world. A simple search on Google with a keyword “safe communities” revealed more than 657,000 entries (Google, 2007b) highlighting the importance given to the building of safe communities. However there is a huge spectrum of definitions of ‘safe’ that were used to describe the ‘safe communities’. Webster’s English Dictionary defines safe as “free from risk or danger” (Webster, 2007).

4.5.1.2 Safer Christchurch Strategy

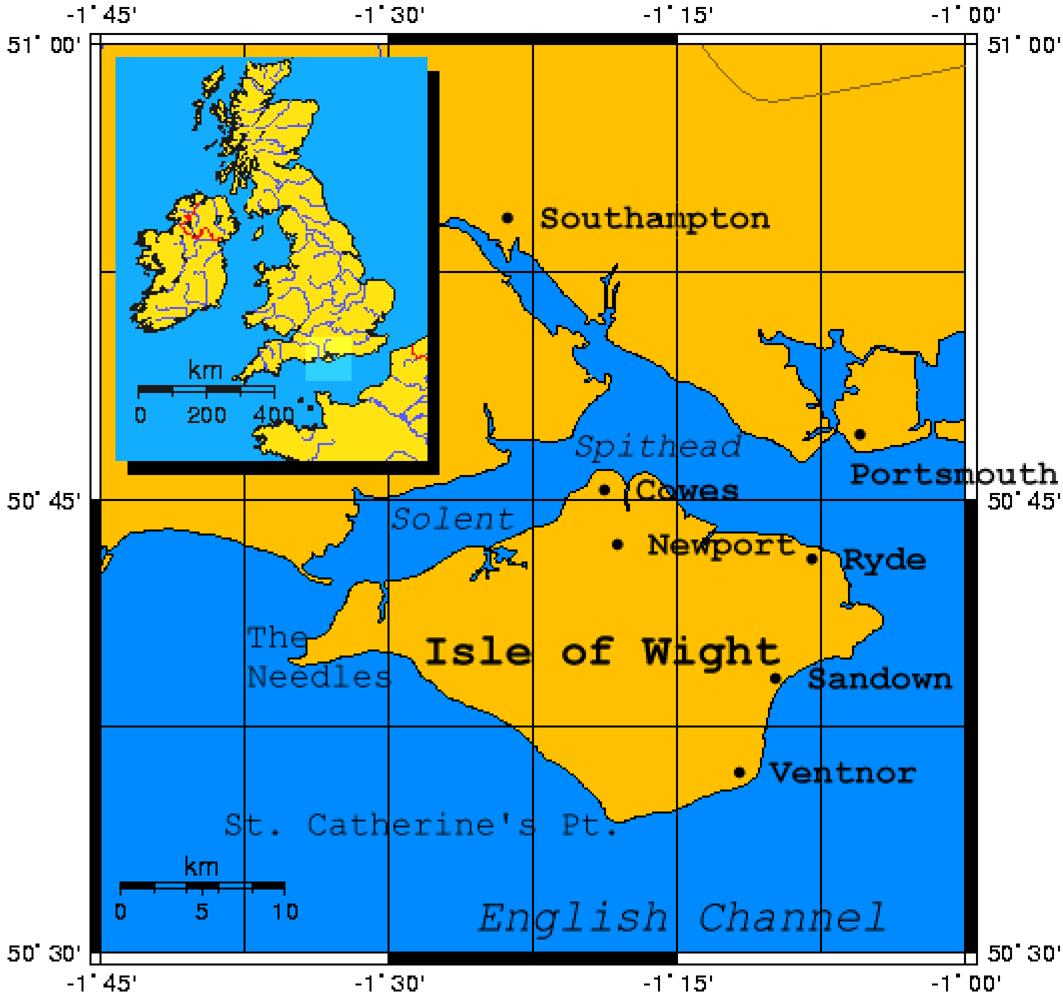
In September 2005, Christchurch City Council published The Safest City In New Zealand Safer Christchurch Strategy (2005) where the Mayor of Christchurch wrote “When it comes down to the nuts and bolts of living our lives, there’s a single, universal wish that we all have – to ‘feel safer’”. The aim of the strategy was to improve the safety of the city by reducing crime and accidents, taking action across the city to address crime and safety issues and their causes.

4.5.1.3 New Zealand

At a national level, the New Zealand Government initiated activities to build safe and secure communities. Addressing Parliament, Justice Minister Hon Mark Burton (2007) stated that the New Zealand government believes every New Zealander should live in a safe and secure community where he or she can take part in all the activities a vibrant society offers, indicating that the 2007 Budget included new funding to build safe communities in the cities of New Zealand

4.5.1.4 Safer Island (UK)

The Isle of Wight is an island off the southern English coast, to the south of the county of Hampshire (see Map 7). Colloquially The Isle of Wight is known as "The Island" by its residents and is the smallest ceremonial county in England at 380 km² and 132,731 permanent residents in the 2001 census. The Island is mainly a rural community, covering an area of 147 square miles and with a coastline of 57 miles



Map 7: Isle of Wight (Wikipedia, 2007)

In 2000 the Isle of Wight set up a Local Strategic Partnership which evolved into the Island Strategic Partnership (ISP) bringing together representatives from across the public, business, voluntary and community sectors. The partnership aim was to ensure that all the partners work to the common goal of creating a sustainable Island community. The Community Strategy is a long-term vision which outlines to develop the Isle of Wight as a Safe and Strong Island under the Island Strategic Partnership by 2020.

The Community Strategy outlines the vision of "A safe and strong Island" by creating an Island where people value and respect one another and feel safe and secure. The Community Strategy explains why the island needs to be developed as a safe and strong island by providing an environment where the community is safe and free from the fear of crime, hence, to improve the quality of life on the Island. Developing communities where everyone feels safe is a priority for the ISP. The Strategy outlines that a safe and strong island would be created by "creating cleaner, greener and safer public spaces, Empowering local people to have a greater voice and influence over decision-making and the delivery of services and building respect in communities and reducing anti-social behaviour" (The Isle of Wight Councils, 2006)

4.5.1.5 Safer Island Development Programme (Maldives)

Following the Indian Ocean Tsunami, the population development programme was revisited and the programme was redeveloped as the Safer Island Development Programme (SIDP). The idea of the Safe Islands concept is to extend the population consolidation approach to incorporate the aspect of extreme vulnerability, and develop measures to mitigate ecological disasters. This will enable the communities to sustain social and economic development in times of emergencies and disasters, by providing ecologically safe zones. These are intended principally to mitigate tsunami hazards and other disasters by establishing building and construction codes that would enable vertical evacuation if and when necessary, and provide all basic services in an emergency, including particularly health, communication and transport infrastructure, as well as ensuring a buffer stock of basic food and water. Figure 20 presents the criteria that were formulated to identify the safer islands by defining the characteristics of a safer island.

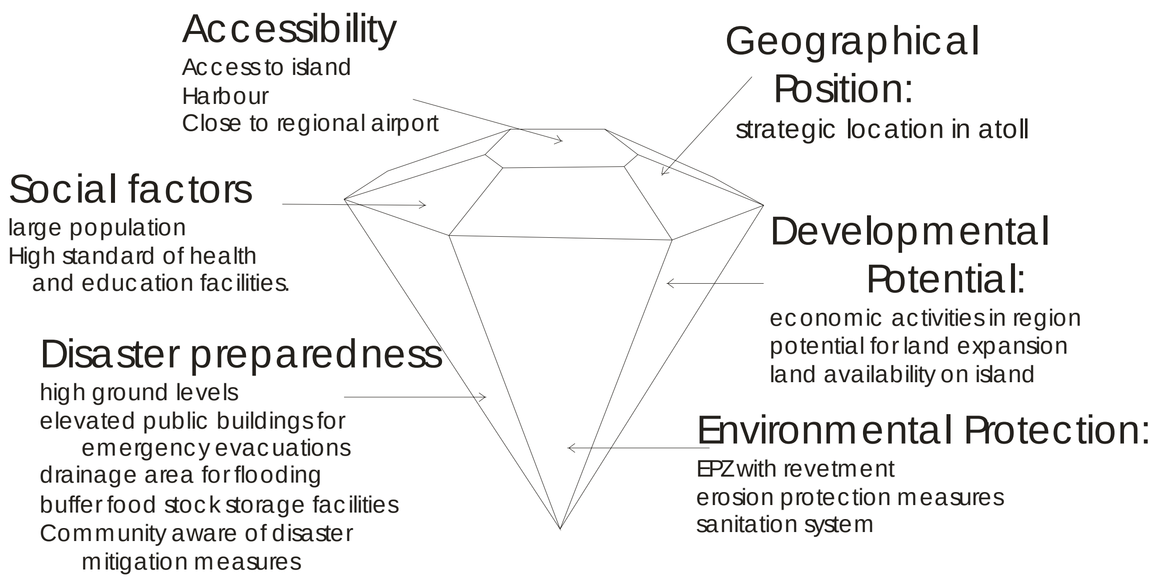
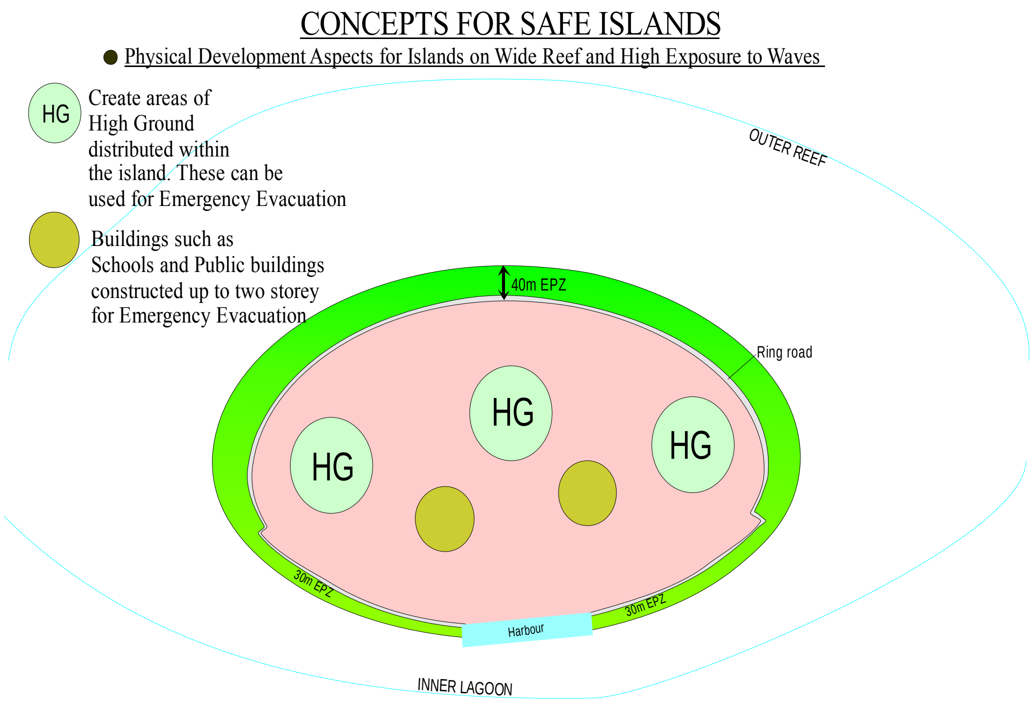


Figure 20: Characteristics of a Safer Island (source: MPND, 2007a)

The SIDP seeks to provide the infrastructure necessary to adapt to climate change and to be better prepared for natural disasters. A Safer Island will have better coastal protection, elevated pubic buildings for vertical evacuation, emergency supplies, an appropriate harbour, and more reliable communications systems. These islands should also serve their neighbouring islands in the event of a disaster. This overarching policy will be the backbone of long-term development and is also in line with the broad government policy of "building back better" following the tsunami. Ideally, consolidation should take place on these Safer Islands (MPND, 2007a).



Presently, the Government of Maldives have identified eleven islands which will be developed as safer islands through out the archipelago. Table 2 gives the list of the eleven islands that have been designated as the safer islands in the Maldives. See Figure 2 for the locations of these islands.

Atoll	Island
HDh	Nolhivaranfaru
Sh	Funadhoo
R	Dhuvaafaru
B	Goidhoo
K	Thulhusdhoo
Adh	Maamigili
M	Muli
Dh	Kudahuvadhoo
Th	Vilufushi
L.	Gan
GA	Vilingili

Table 2: The islands that have been designated as Safer Island in the Maldives (source: MPND, 2007a)

5 Methodology

This chapter will presents detailed aims and objective of the study and outlines the study methodology. The chapter will present the model which integrates the management of critical disasters in the Sustainable Development Planning of the Maldives

5.1 Hypotheses

The success of the Safer Islands Development Programme depends on the level to which the resilience of the communities could be enhanced by including disaster risk mitigation in the tsunami reconstruction programme currently underway in the Maldives. Understanding the factors which make the islands vulnerable to such events would help to reduce the level of exposure of the community to risk.

Recent disasters and extreme events show that the levels of impact on the islands from such events have a spatial distribution; an island's vulnerability depends on its geographic location and geomorphology. Geographic features include location of the island, reef of the island, spatial distributions of the reefs and islands which shadow or obstruct the approaching wave and source of tsunami, which controls the characteristics of the tsunami such as direction and magnitude. Geomorphological factors include width and orientation of the reef, which protects the island, shape (Yeh et. al, 1994), and size of the island (Kench et. al, 2006) and height of the island's bund, which is the physical barrier protecting the island from overtopping of waves onto the island.

The level of impacts also depends on socioeconomics of the islands, such as the level of physical development on the island's beach (e.g. building of harbours or modification to the beach (or coastline) by building sea walls, key walls, breakwaters, solid jetties or reclamation on the island).

5.2 Objectives

The main goal of this thesis is to identify and quantify the risks of hazards and disasters that may significantly impact the socioeconomic and physical environment of the Maldives.

The objectives of this research are:

- to develop a set of indicators to assess the environmental vulnerability of islands using the geophysical, social and economical characteristics of the islands for climatic and non climatic disaster risk,
- to identify the appropriate tools which can be used in environmental planning, so as to minimise the degree of risks to the socio economic and physical environment of the Maldives, and
- to identify vulnerable islands to disasters with specific needs such as to avoid physical development on these islands to enhance the resilience of the island communities.

5.3 Methodology

The success of the Safer Islands Development Programme depends on the level to which the resilience of the communities could be enhanced by including disaster risk mitigation in the tsunami reconstruction programme currently underway in the Maldives. Understanding the factors which make the islands vulnerable to such events could help to reduce the level of exposure of the community to risk.

5.3.1 Research Approach for the Assessment

Figure 21 presents the methodological framework adopted for the study to determine the natural physical vulnerability of the island. In stage 1 of the study, an Island Vulnerability Index is developed. The Island Vulnerability index is a function which depends on an island's natural vulnerability due to its natural physical characteristics, building vulnerability due to the built environment on the island and the human vulnerability due to the human environment of the island.

Methodological Framework for Assessment

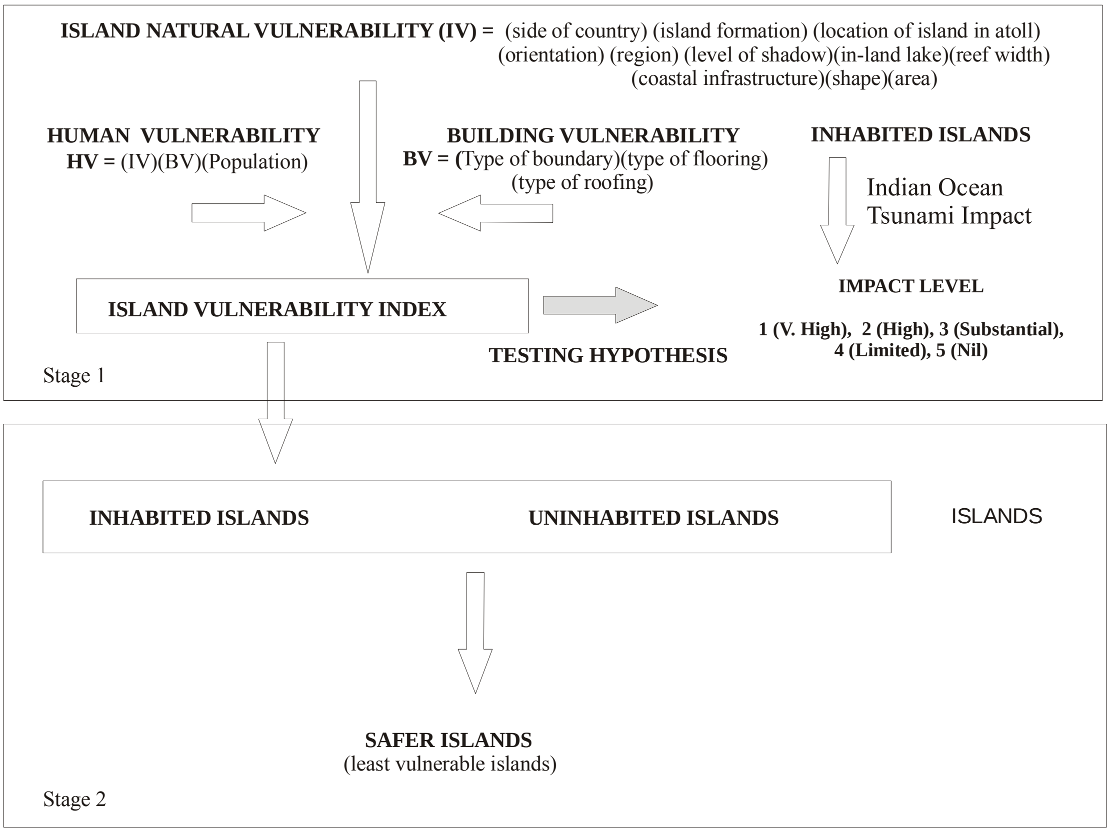


Figure 21: Methodological Framework for Vulnerability Assessment

The Island Vulnerability Index will be tested for the inhabited islands (204 islands) using the damage assessment data that was collected following the Indian Ocean Tsunami. The testing of the Index will be done by trying to simulate the Impact Level (i.e. the damage) that was caused by the Indian Ocean Tsunami. Then, the Index will be used for all islands (1035 islands) (ie both inhabited and uninhabited islands) to identify the least vulnerable islands.

Figure 22 illustrates the research framework adopted for the study. The following sections provide details of the framework, including the sources of the information, techniques that were used for the data processing, analysis, interpretation and presentation of the findings of the study.

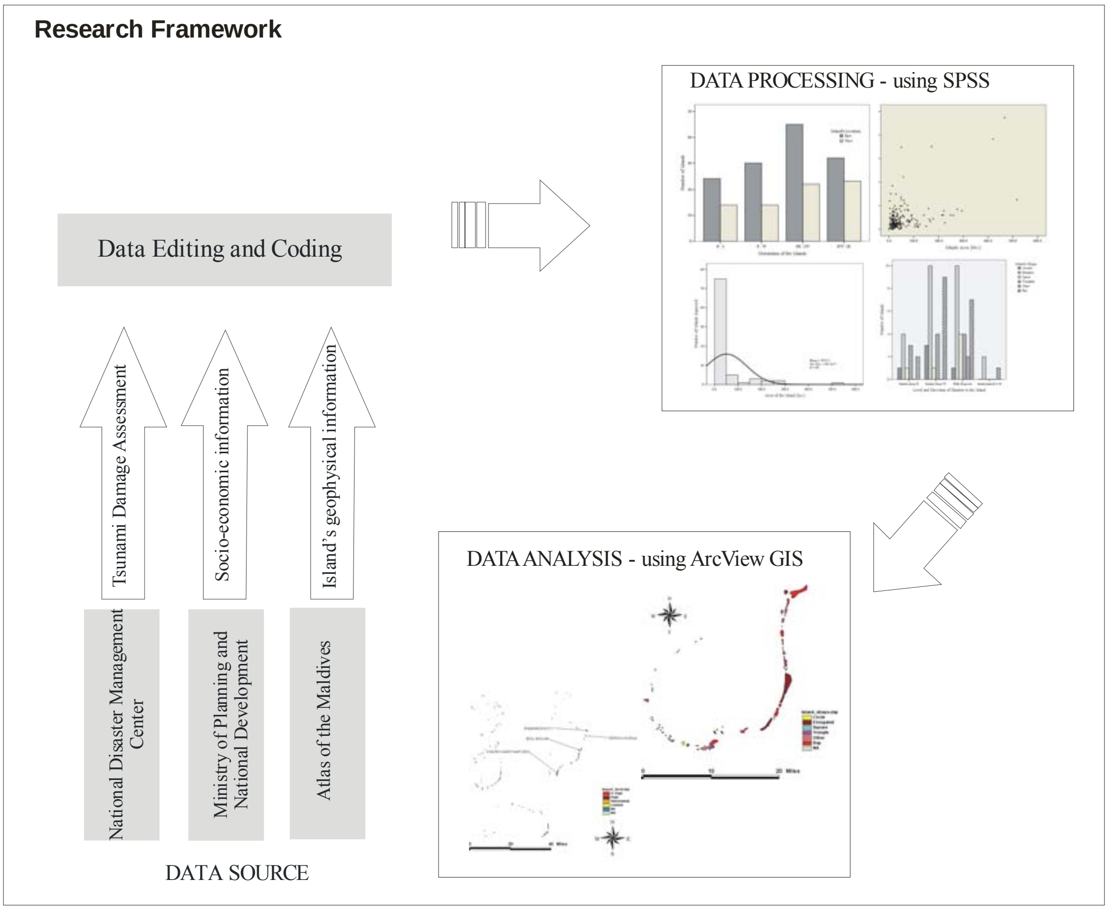


Figure 22: Research Framework adopted for the study

5.3.2 Materials, Methods and Database

5.3.2.1 Data from the Inhabited Islands

Within hours after the tsunami struck, the Ministry of Environment and Construction developed a questionnaire, which was used by the National Disaster Management Centre to call affected islands and assess the extent of damage to water, sanitation, and waste, coastal and other environmental infrastructure. The National Disaster Management Centre provided the information which was collected from 204 inhabited islands. The National Disaster Management Centre, provided the collected information, from the 204 inhabited islands, for use in this assessment. Descriptions of this information are given in Table 3.

Indicator	Impact Level
Ground water	usable (1), usable (0)
Drinking water	available (1), not available (2), needed (3)
Debris	lot (1), not too much (2), none (3)
Breakwaters	damaged breakwaters (m)
Sea Wall	damaged sea wall (m)
Harbour	dredged area of harbour became shallow (sqm)
Housing & Infrastructure	no damage (1), 3/4 damage (2), 1/2 (3), 3/4 (4), full (0)
Jetty	damaged (1), no damage (0) and damage length (m0
Harbour Entrance	became shallow (1), did not become shallow (2), area to be deepened (sqm)
Beach	eroded (1), not eroded (2), eroded area (sq m)
Road	damaged (1), no damage (0), damage road length (m)
Cause way	damaged (1), no damage (0), damage road length (m)

Table 3: Data Collected for Assessing the Impacts of Tsunami on Inhabited Islands

5.3.2.2 Tsunami Impact Assessment 2005

The Tsunami Impact Assessment (2005b) focussed on the effect of the vulnerability and poverty status on the effects of the tsunami on households of both the tsunami impacted and not impacted inhabited islands. The survey covered ten households on each inhabited island, but used a larger sample size in the more heavily populated islands. In total 2,400 households were surveyed, covering a wide range of socioeconomic characteristics. The assessment covered one-third of inhabited islands, covering tsunami specific information from the 14 most-affected islands and 54 islands – those where at least one-third of households had received tsunami assistance

(WB et al., 2005). A summary of the information categories collected in the survey are given in table 4.

Impact	Indicator (number of household)	Impact	Indicator (number of household)
Household Well Water	Well water became salty	Economic Impact	Income changed due to tsunami
	Well water has been contaminated		Income decreased after tsunami
	Well water status is others		Income did not change after tsunami
Drinking Water	Having a water tank		Income discontinued/stopped after tsunami
	Water tank storage (L)		Income increased after tsunami
	Drinking mineral water		Joint family business had to be stopped due to tsunami
	Drinking water from other sources		Joint family business was not stopped due to tsunami
	Drinking well water from the mosque		Smell and colour has changed in well water
	Drinking water from private rain water tank		Smell and colour of well water changed
	Drinking water from public rain water tank	Housing	Total number of rooms before tsunami
	Drinking water from rain water tank in the compound		Completely destroyed
	Drinking water from the public piped supply		Damaged due to tsunami
	Drinking water from well in the compound		Water was contaminated
	Well water in good condition		Damage to the kitchen
	Other problems with the well water		Damages to the toilet septic tank
	Damage to water tanks		Damage to the roof
Sanitation	Sanitary problems		Ground pitted
	Well water was contaminated due to tsunami		Other damages
	Cracks on the wall		Number of persons living with relatives due to tsunami displacement
Cost of Construction	Repair of a room (pre & post tsunami), rebuilt or repair a part of house (pre & post tsunami)		Damage to the boundary walls

Table 4: Tsunami Impact Survey 2005 (data provided by MPND)

5.3.2.2.1 Tsunami Impact Level

The Tsunami Impact Assessment Survey (2005b) used five categories to rank the level of impact on the tsunami affected islands. These ranged from ‘very high” in those islands which were evacuated to “nil” in the unaffected islands. These five categories are described in Table 5.

Code	Definition	Description	Number of Islands
1	V. High	Population displaced and temporary shelter required	14
2	High	Population displaced and major damage to housing and infrastructure	22
3	Substantial	Damage to more than a quarter of buildings and infrastructure	33
4	Limited	Flooding in few houses but no structural damage	122
5	Nil	No Flooding	9

Table 5: Tsunami Impact Categories

5.3.2.3 Population and Housing Census 2006

The Ministry of Planning and National Development provided the information in Table 6 which was collected in Population and Housing Census 2006 (Census 2006). The Census 2006 was carried out in all the 196 administrative islands, 87 resort islands and 34 industrial and other islands of the country. It collected data relating to the size, geographical distribution and socio-economic characteristics of the population such as sex, age, educational attainment, marital status and employment. The Census 2006 administered four questionnaires for data collection, namely: Household Listing Form, Person's Listing Form, Household Form (includes household and persons information) and Establishment Form. This census was originally planned for the year 2005, but was postponed to 2006 due to the tsunami (MPND, 2006a).

Indicator	Number of Houses
Population	Male, female, migrant, non migrant
Reasons for Migration	To live temporarily due to tsunami, To live Permanently due to tsunami and due to population consolidation program
Wall type of houses	Bricks and plastered, bricks unplastered, durable wood / wooden sheets, ordinary thin plywood and wood slides, thatch and sticks and others
Floor type of houses	Cement / slake lime, tiles, concrete sheet, durable wood, sand and other
Roof type	Gulvanized tin sheets, thatch, roofing tiles, concrete sheets, wood and other
Drinking water	Rain water, well water, desalinated water, water bottles and other
Life Style Accessory	TV, cable TV, air conditioner, phone line, internet
Employment	Employed, not employed and inactive
Industry	Agriculture forestry, fishing, quarrying, manufacturing, electricity gas water, construction, whole sale retail trade, hotels restaurants, transport storage communication, financial intermediation, real estate renting and business activities, public administration and defence, education, health and social work, community social and personal services and extra territorial organisations and bodies

Table 6: Census 2006: Island Level Information (source: MPND, 2006a)

5.3.2.4 Base Map of the Maldives

In 2005, following the Indian Ocean Tsunami, UNDP commissioned a study on Developing a Disaster Risk Profile for Maldives (UNDP, 2006) for a comprehensive examination of where the risks from multiple hazards are concentrated in the Maldives and also, who are most affected by them. The study focused on two main components of risk assessment comprising multi-hazard assessment and vulnerability assessment. The study created a digital base map of Maldives comprising island boundaries and their attribute information. Information of 1037 islands was captured using remote sensing images. The base map is fundamental to the Geographic Information System (GIS) analysis of this study and the base map was provided by UNDP to undertake this research project.

5.3.2.5 Training for the use of GIS

Water Solutions Pvt Ltd provided me with training on how to use ArcView 7.0. The training helped me to use the base map of the Maldives and to create layers of the data which was collected for the project. This study used GIS for spatial analysis and the results in this research are presented in 6.5.5.1.

5.3.2.6 Geometric Variables Measured from the Atlas of the Maldives

The geometric variables of the islands such as the island's location with respect to the side of the country and with respect to the atoll was obtained from the Atlas of the Maldives (2004). The information of the island regarding its region of the country, island use and island category was obtained from the Ministry of Planning and National Development. The information for the island formation was obtained from Atlas of the Maldives (2004) and (Google, 2007a).

5.3.2.6.1 Side of the Country

The location of the island with respect to the side of the country is an important parameter which determines the vulnerability of the islands by providing shelter from a approaching tsunami. The atolls in the Maldives are arranged as a double chain in the central region, tapering off towards north and south to a single atolls. In the central region, some atolls are located in the western side of a line of atolls, thereby being protected from the direct impact of the tsunami waves.

The location of an island has been classified according to whether the island is located on the eastern side or western side of the country. This classification is shown in Figure 23. This classification was used to islands which were found in atolls which are located in a single chain in the northern and southern region of the Maldives. However weighting was given in the analysis of data as such that all the islands were given high scores as these atolls have no shelter from an atoll.

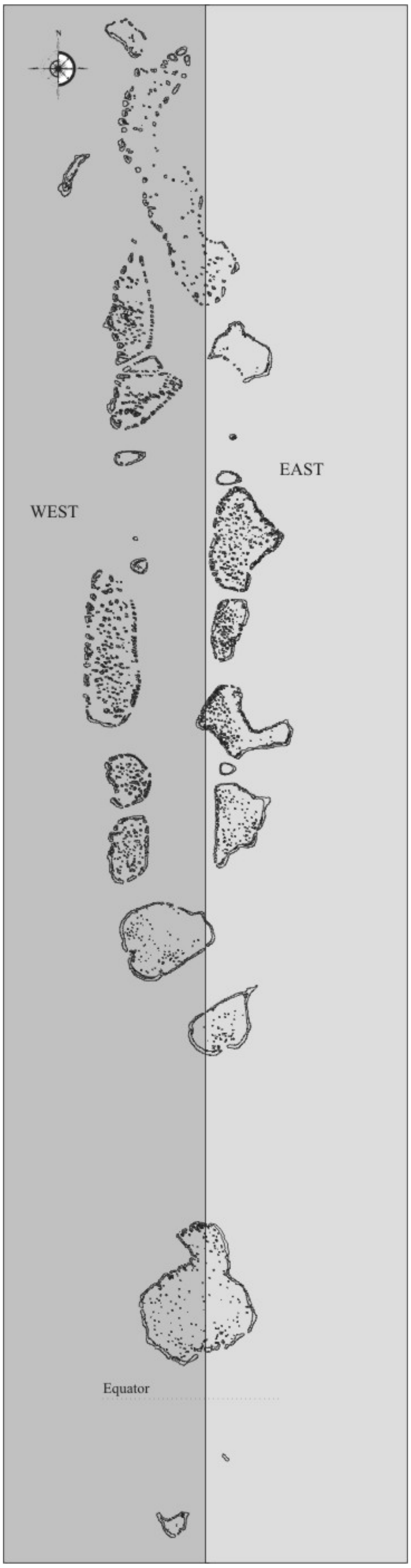


Figure 23: Classification of Islands - Side of Country

5.3.2.6.2 Region of Country

The 6th National Development Plan of the Maldives established regional development centres in the Maldives by categorising all the islands into 5 centres. Table 7 shows these regional classifications and the distribution of the islands into these regions.

Regions	Atoll	Number of Island		
		Inhabited	Unihabited	Total
North	Haa Alifu	16	27	43
	Haa Dhaalu	17	20	37
	Shaviyani	16	32	48
North Central	Noonu	13	54	67
	Raa	15	71	86
	Baa	13	53	66
	Laviyani	5	49	54
Central	Kaafu	11	74	85
	Aalifu Aalifu	8	25	33
	Aalifu Dhaalu	10	39	49
	Vaavu	5	20	25
South Central	Meemu	9	26	35
	Faafu	5	16	21
	Dhaalu	9	34	43
	Thaa	13	51	64
	Laamu	12	48	60
South	Gaafu Alifu	10	78	88
	Gaafu Dhaalu	10	92	102
	Gnaviyani	1	0	1
	Seenu	6	24	30
		204	833	1037

Table 7: Development Regions

Figure 24 shows the development regions that have been outlined in the 7th National Development Plan of the Maldives (MPND, 2007b).

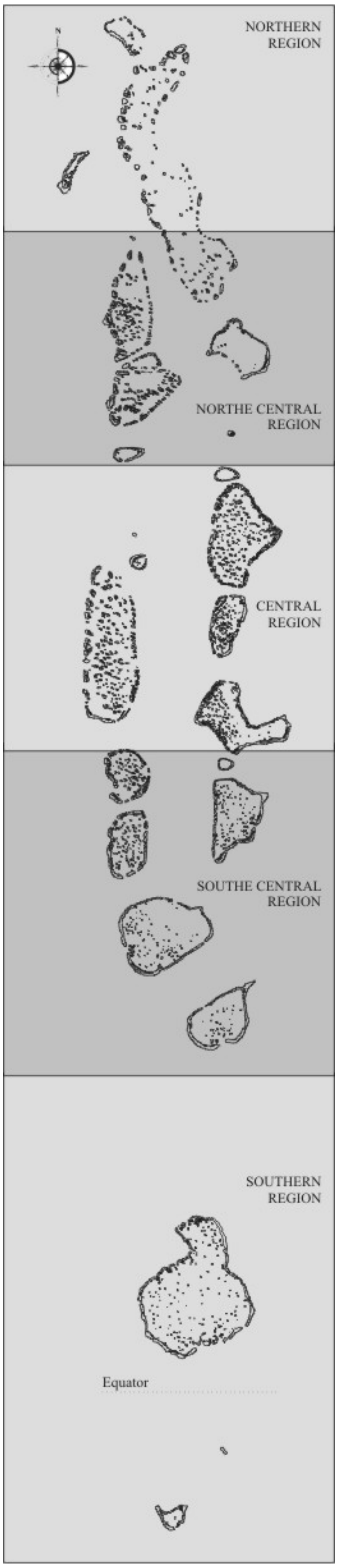


Figure 24: Classification of the Regions in the Maldives

5.3.2.6.3 Island Formation

Naseer (2003) outlined seven geomorphological zones in the islands and reefs of the Maldives. See Figure 25.

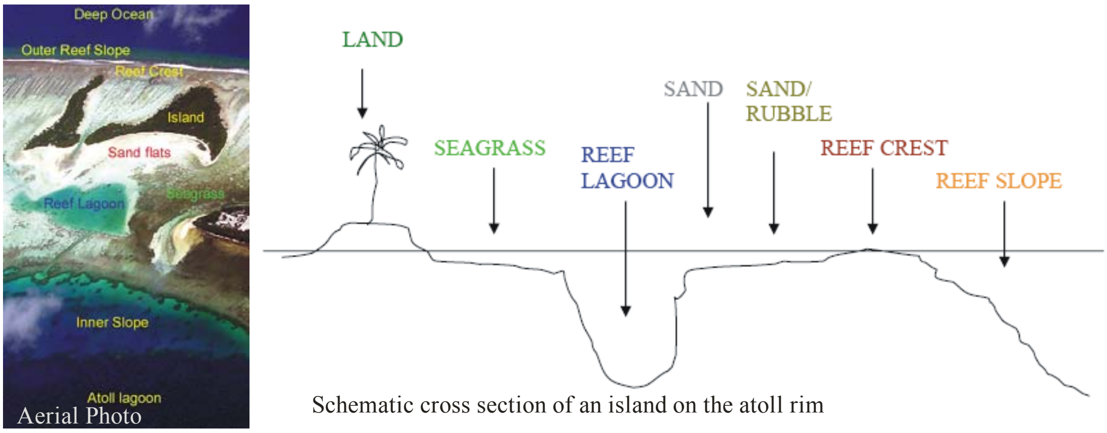


Figure 25: Seven geomorphological classes of an island found on the rim of an Atoll (adopted from (Naseer, 2003)

Based on the seven geomorphological zones, lagoon is a well defined geomorphological feature on islands in the Maldives. They are found on both islands which are located on the atoll's rims and inside the atoll (Naseer, 2003). A lagoon in this study is defined as island which has lagoon that has a minimum depth of at least 3 – 5 meters.

Figure 26: Aerial photo of Villivaru and Biyadhoo, to emphasize the island formation structure of islands found inside the atoll in the Maldives which was adopted for the study

The Atlas of the Maldives was used to classify the islands into two categories; islands with a lagoon and islands without a lagoon.

5.3.2.6.4 <u>Location within the Atoll</u>

The atolls in the Maldives are arranged such that some atolls are located in the western side of a line of atolls, thereby being protected from the direct impact of the tsunami waves. Even the atolls in the eastern side, because of the ring-type formation, have islands on the eastern fringe of the atoll exposed to the incoming waves and island on the western fringe, which are more protected by the eastern fringe reef flat. Also there are islands in the centre of the lagoon of the ring-type atolls. Likewise, islands located in the western atolls (i.e the atolls which are located on the western side of the country) have been classified into three categories, east fringe, west fringe and the central lagoon.

The location of an island within the atoll was defined on whether the island was located on eastern side (east fringe) or western side (west fringe) or inside of the atoll (central lagoon). Figure 27 shows how the definition of the islands within the atoll was used to categorise the islands for this study.

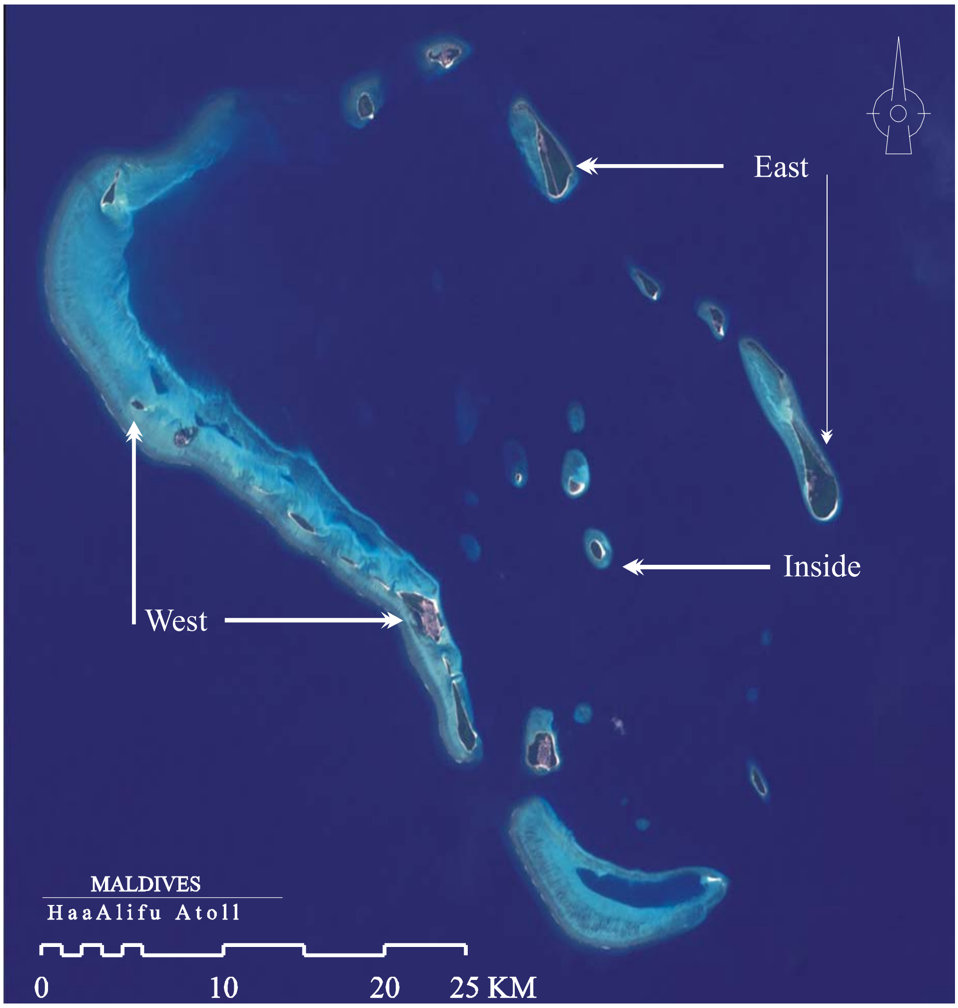


Figure 27: Definition of the Island's Location within Atoll

5.3.2.6.5 Length of the Island's House Reef flat

The reef widths were measured such that the length, measured from the shoreline to the reef edge, is approximately perpendicular to the wave crest as shown in Figure 28. An assumption is made such that the a tsunami is approaching the island from the east. The reef widths used are the average of widths measured from both the Admiralty Charts and scaled aerial photographs of the Maldives.

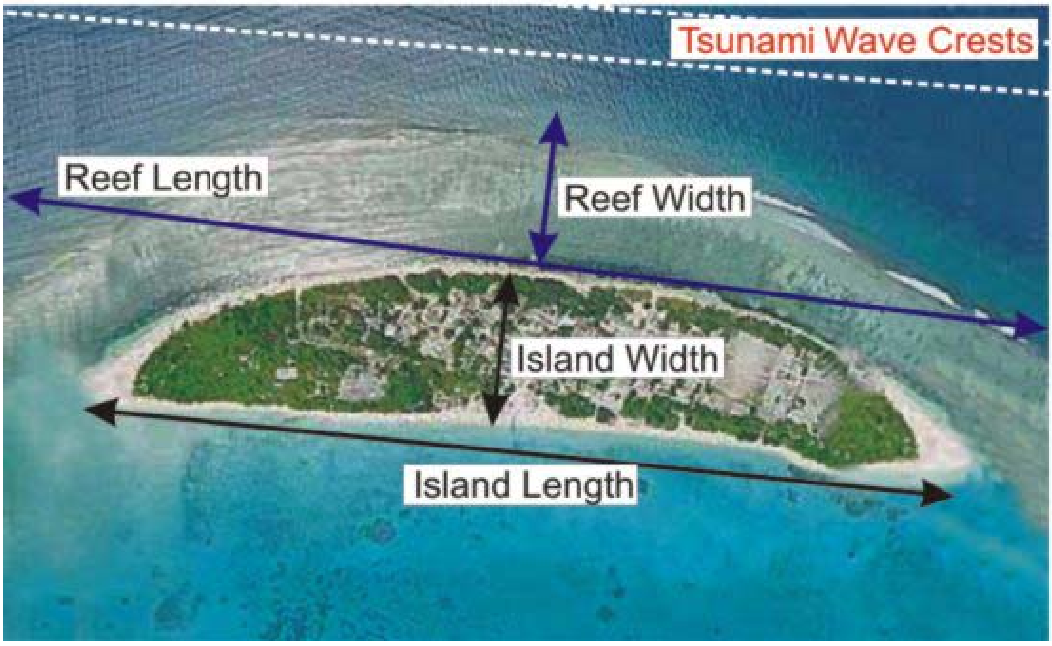


Figure 28: Definition of the Reef Length, Reef Width, Island Width, Island Length (adopted from Ali, 2005)

5.3.2.6.6 Length of Island's House Reef

An island's house reef length was measured from the Maldives Admiralty Charts and Atlas of the Maldives (2004). Figure 28 gives the definition of the reef length which was measured. Length between deep channels was measured as the reef length in the atoll fringes. Where possible the reef lengths that were parallel to the wave crest was measured.

An atoll is best characterized by its *rim* and the central *lagoon*. Reefs within the atoll lagoon are sheltered from high energy, wave and swell regimes to which all rim reefs are constantly subject, depending, in the northern Indian Ocean, on the status of the monsoon.

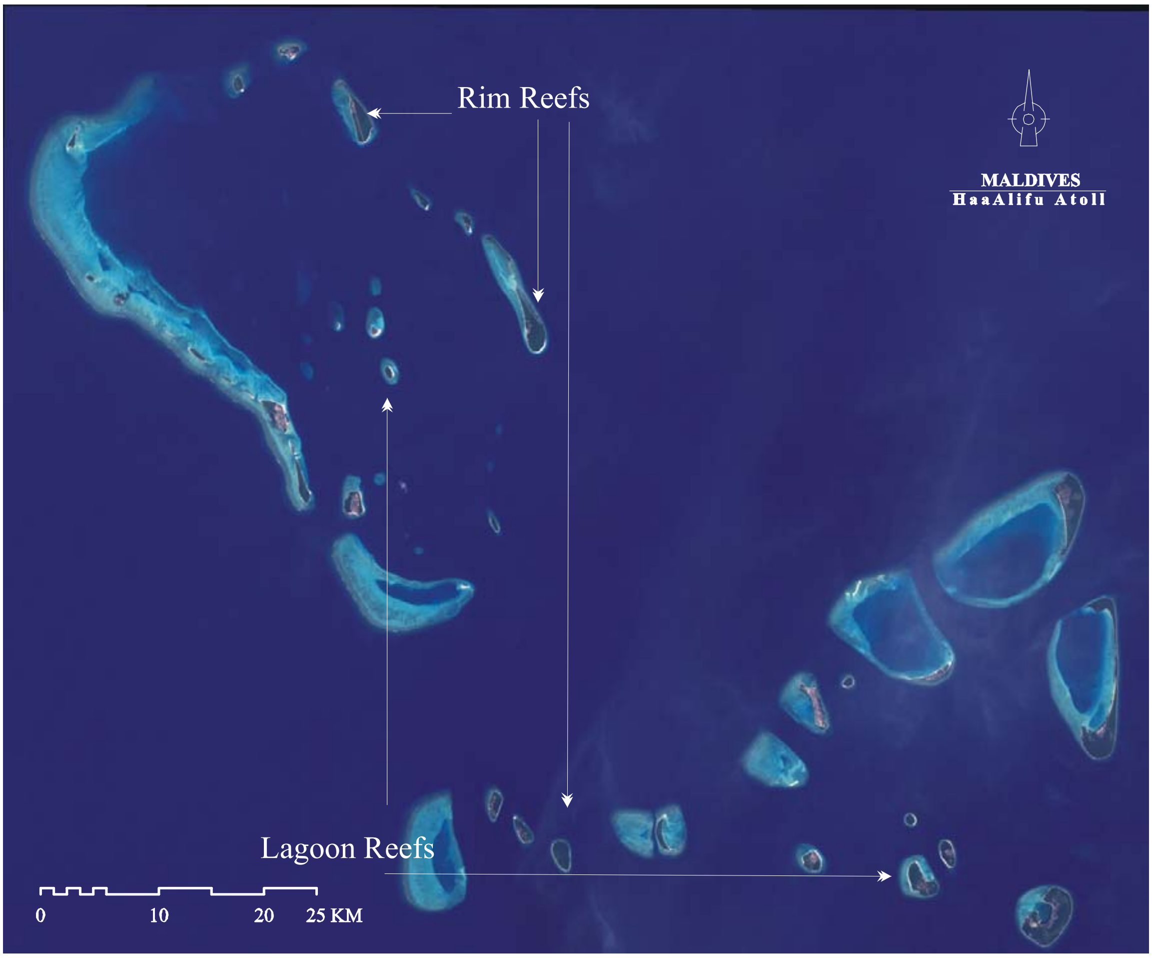


Figure 29: Satellite image of Haa Alifu atoll in the Maldives to illustrate the main geomorphic components of a typical Maldivian atoll (reproduced from Google Earth)

5.3.2.6.7 Island Category

The *island category* is an important parameter used to classify the islands in the Maldives. The islands are broadly categorised as inhabited and uninhabited islands. Inhabited islands are islands where people live and have an administration office which takes the responsibility of taking care of the community on the islands. Uninhabited islands are all other islands.

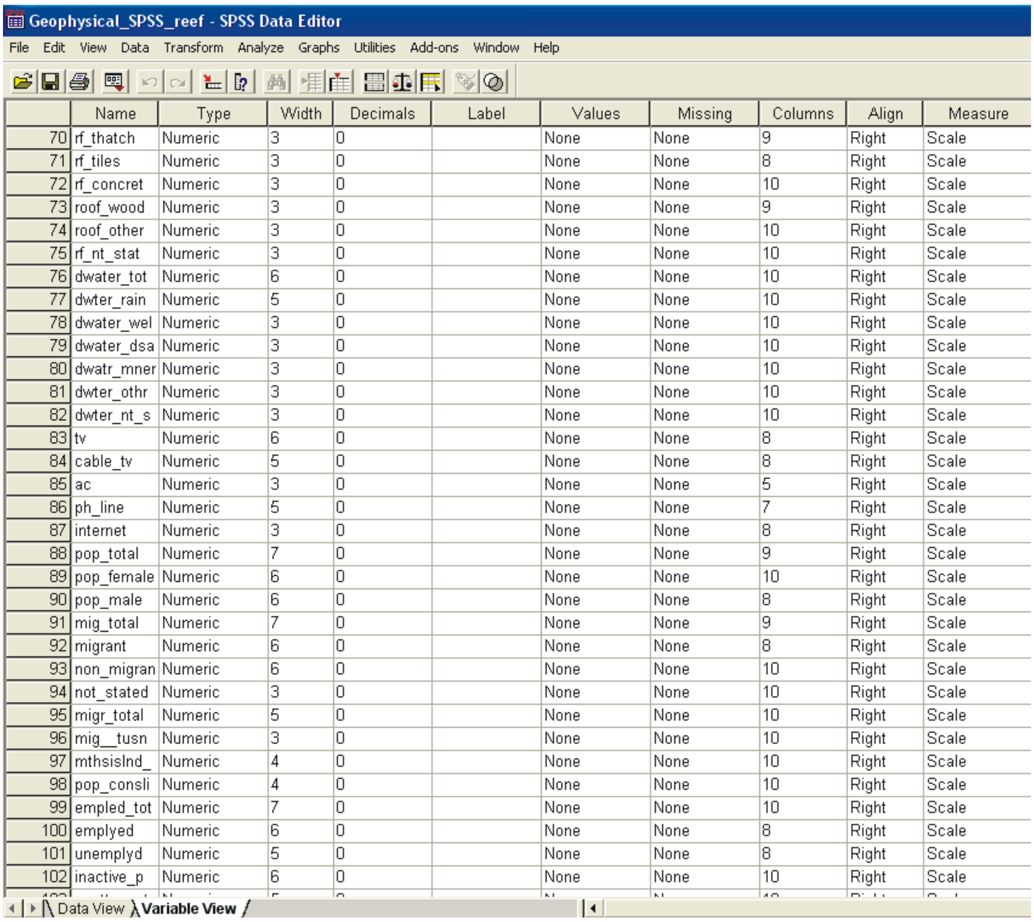
For the purpose of this project, uninhabited islands are those islands which are not considered as inhabited islands in the base map of the Maldives that was developed by UNDP (2006).

5.3.2.6.8 Island Use

The island use was categorised as residential, resort, agricultural, airport, industrial and other use. The information on the island used was obtained from Ministry of Planning and National Development using the information collected for the Population and Housing Census 2006.

5.3.3 Data Processing

The data which was collected from the National Disaster Management Centre, Ministry of Planning and National Development and Atlas of the Maldives was first coded to ensure it could be input to SPSS. Coded data was entered using Microsoft Excel 2007 and converted to 'dbf4' format. The 'dbf4' converted data was then used in SPSS for data processing.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure
70	rf_thatch	Numeric	3	0		None	None	9	Right	Scale
71	rf_tiles	Numeric	3	0		None	None	8	Right	Scale
72	rf_concret	Numeric	3	0		None	None	10	Right	Scale
73	roof_wood	Numeric	3	0		None	None	9	Right	Scale
74	roof_other	Numeric	3	0		None	None	10	Right	Scale
75	rf_nt_stat	Numeric	3	0		None	None	10	Right	Scale
76	dwater_tot	Numeric	6	0		None	None	10	Right	Scale
77	dwter_rain	Numeric	5	0		None	None	10	Right	Scale
78	dwater_wel	Numeric	3	0		None	None	10	Right	Scale
79	dwater_dsa	Numeric	3	0		None	None	10	Right	Scale
80	dwatr_mner	Numeric	3	0		None	None	10	Right	Scale
81	dwter_othr	Numeric	3	0		None	None	10	Right	Scale
82	dwter_nt_s	Numeric	3	0		None	None	10	Right	Scale
83	tv	Numeric	6	0		None	None	8	Right	Scale
84	cable_tv	Numeric	5	0		None	None	8	Right	Scale
85	ac	Numeric	3	0		None	None	5	Right	Scale
86	ph_line	Numeric	5	0		None	None	7	Right	Scale
87	internet	Numeric	3	0		None	None	8	Right	Scale
88	pop_total	Numeric	7	0		None	None	9	Right	Scale
89	pop_female	Numeric	6	0		None	None	10	Right	Scale
90	pop_male	Numeric	6	0		None	None	8	Right	Scale
91	mig_total	Numeric	7	0		None	None	9	Right	Scale
92	migrant	Numeric	6	0		None	None	8	Right	Scale
93	non_migran	Numeric	6	0		None	None	10	Right	Scale
94	not_stated	Numeric	3	0		None	None	10	Right	Scale
95	migr_total	Numeric	5	0		None	None	10	Right	Scale
96	mig__tusn	Numeric	3	0		None	None	10	Right	Scale
97	mthsislnd_	Numeric	4	0		None	None	10	Right	Scale
98	pop_consli	Numeric	4	0		None	None	10	Right	Scale
99	empled_tot	Numeric	7	0		None	None	10	Right	Scale
100	emplyed	Numeric	6	0		None	None	8	Right	Scale
101	unemplyd	Numeric	5	0		None	None	8	Right	Scale
102	inactive_p	Numeric	6	0		None	None	10	Right	Scale

Figure 30: Variable View of the SPSS Statistical Package used for the data entry and editing

5.3.4 Data Analysis

5.3.4.1.1 Standardised score

The qualitative data were used for the calculation of the different vulnerabilities of the islands. The first step was the standardisation of the raw data collected using the following formula.

$$\text{Standardized score iv} = \frac{\text{raw score iv}}{\text{maximum (High Vulnerable) raw score iv}} \quad \textbf{(1)}$$

Standardisation was carried out for the island natural vulnerability, building vulnerability and human vulnerability calculations.

Criterion	Definition (score)	Standardisation	Remarks
Side of the country	1-East, 2-West	(score) / 2	islands on the east are more vulnerable
Formation	1-with lagoon, 0- without lagoon	(score) / 1	islands with lagoon shaollower area for the water to pile up and increase in height of the wave and hence are more vulnerable than islands without a lagoon
Location within the atoll	1 - Inside, 2 - Atoll east, 3 - Atoll west	(score) / 3	Islands inside the atoll are less vulnerable
Orientation of the island	1 - North-South, 2 - East-West, 3 - NE-SW, 4 - NW-SE	(score) / 3	north-south oriented islands are less vulnerable than islands which have other direction of orientation (see section 6.2.4)
Region	1-North, 2- North Central , 3-Central, 4-South Central, 5-South	(score) / 5	islands in southern region are more vulnerable
Level of shadow	1- shadow from E, 2- shadow from W, 3 no shadow, 4 - shadow from E & W	(score) / 4	fully exposed islands are more vulnerable
in-land Lake	area of the lake	1 / (area)	islands with large lakes are less vulnerable
house reef width	width of the reef	(score) / highest score	islands with wider reef are more vulnerable (it provides a bigger area for the water to pile up and increase in height causing higher inundation)
Sea defence	length of sea defence structures	(score) / highest score	islands with greater coastal structures are more vulnerable as natural shorelines and land surfaces have less impact from tsunami
Shape of the Island	1 - circle, 2 - elongated,3 - square, 4 - triangle, 5 - other, 6 - bay	(score) / 6	islands with 'bay' are more vulnerable
Area	Area of the islands	1 / (score)	smaller islands are more vulnerable

Table 8: Standardisation rules

5.3.4.2 The Island Natural Vulnerability

An island's Natural Vulnerability depends on geographic and geomorphologic characteristics of the island. These include geographic features of the island like the side of the country where the island is located, the formation of the island, location of the island respect to the atoll, orientation of the island, region of the country where island is located, level of shadow to the island from the reefs and other islands; area of the inland lake found on the island, width of the island's house reef, coastal defence structures on the island, shape of the island and the area of the island.

Since the factors do not affect vulnerability equally, they have to be ranked according to their importance. A sensitivity analysis was carried out to find the influence of the weighting on the Island Natural Vulnerability calculations.

5.3.4.2.1 Sensitivity Analysis

A sensitivity analysis was undertaken using the weighting factors scenarios as presented in Table 9 using the equation 2.

Criterion	Weighting Factor Scenarios			
	A	B	C	D
Formation	10	5	11	11
house reef Width	4	8	10	10
Shape of the Island	2	7	4	9
Side of the Country	11	11	8	8
Location within the Atoll	9	4	7	7
Area	1	3	6	6
Orientation of the Island	8	10	5	5
Region of the Country	7	6	9	4
Level of shadow	6	9	3	3
in-land Lake	5	2	2	2
Sea defence	3	1	1	1

Table 9: Weighting factors used in the sensitivity analysis

The importance of the criteria is connected with the level of influence the factors have on the island's natural vulnerability (see section 6.2) and with the mitigation measures that may be taken. Low weighting was given to characteristics on which humans can have greater influence. These include area, shape and coastal defence structure of the island where the area and shape of the island can change by land reclamation and coastal defence can be changed by the development of the coastal line.

Figure 31 presents the model simulations for Weighting Factor Scenarios A, B, C and D as presented in Table 9.

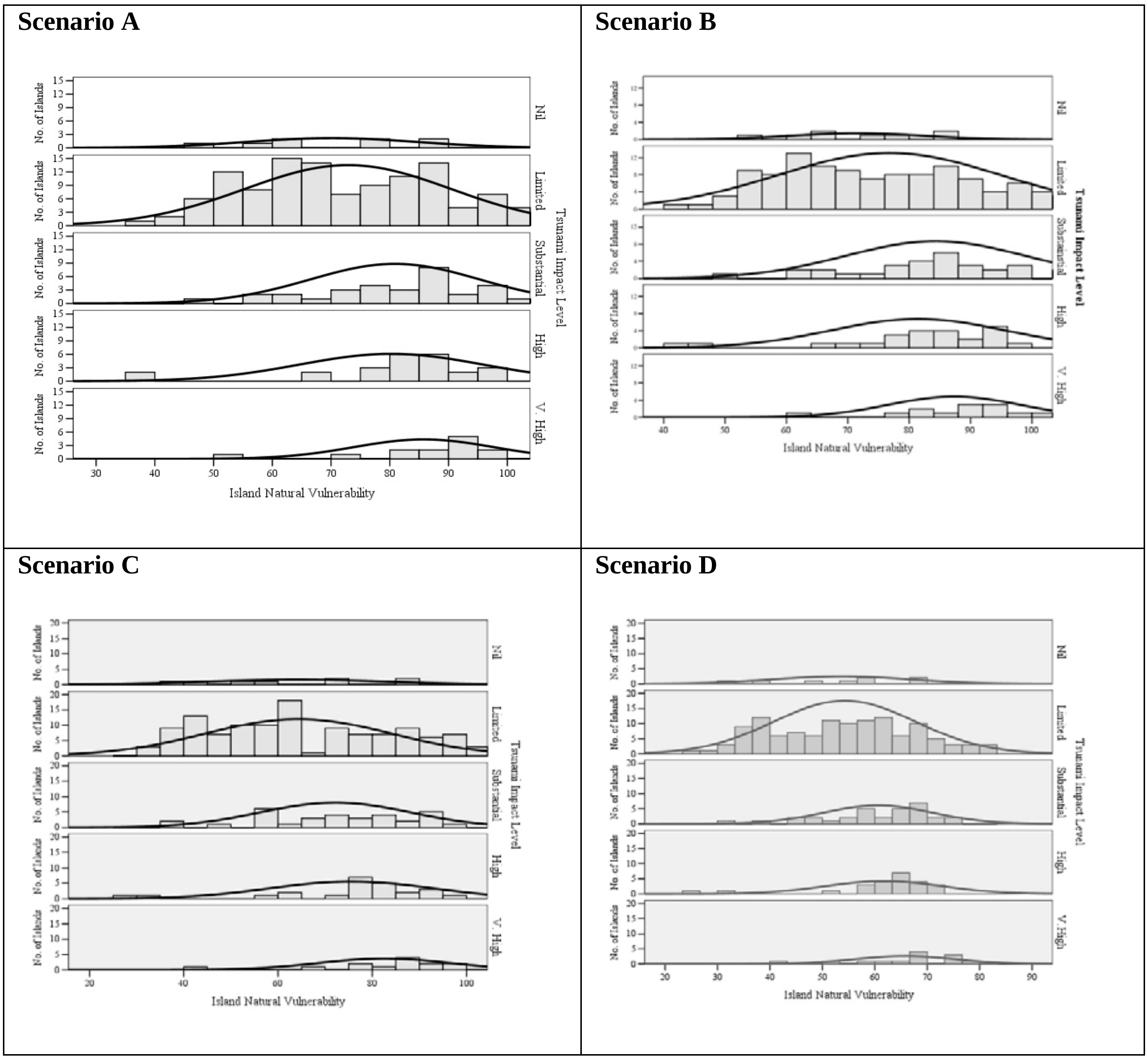


Figure 31: Island Natural Vulnerability against the tsunami impact level for different scenarios

Scenario D was found to represent the observed tsunami impact level following the Indian Ocean Tsunami. Hence the weighting used in the scenario D was used in Eqauation 2 and has been presented in Table 10.

5.3.4.2.2 The Island Natural Vulnerability

The criteria were arranged in order of importance and a weight factor was applied (Table 10).

$$IV = (11xa)+(10xb)+(9xc)+(8xd)+(7xe)+(6xf)+(5xg)+(4xh)+(3xi)+(2xj)+(1xk) \quad \textbf{(2)}$$

Where:

(a) the standardised score that is related to the formation of the island;

(b) the standardised score that is related to the width of the island's house reef;

(c) the standardised score that is related to the shape of the island;

(d) the standardised score that is related to the side of the country;

(e) the standardised score that is related to the location of the island respect to the atoll;

(f) the standardised score that is related to the area of the island;

(g) the standardised score that is related to the orientation of the island;

(h) the standardised score that is related to region of the country;

(i) the standardised score that is related to level of shadow to the island from the reefs and other islands;

(j) the standardised score that is related lake at the island;

(k) the standardised score that is related to the coastal defense structures on the island;

Criterion	Weight factor
Formation	11
house reef Width	10
Shape of the Island	9
Side of the Country	8
Location within the Atoll	7
Area	6
Orientation of the Island	5
Region of the Country	4
Level of shadow	3
in-land Lake	2
Sea defence	1

Table 10; The criteria, their ranking and weight factor for Island Natural Vulnerability

5.3.4.3 The Building Vulnerability (BV)

The qualitative data were used for the calculation of the Building Vulnerably of the islands. The first step was the standardisation of the raw data collected using Equation 1.

$$BV = (3xa) + (2xb) + (1xc) \qquad \textbf{(3)}$$

Where:

(a) the standardised score that is related to the type of boundary marking of building;

(b) the standardised score that is related to the flooring of the building;

(c) the standardised score that is related to the roofing of the building;

Since the factors do not affect vulnerability equally, they have to be ranked according to their importance. The criteria were arranged in order of importance and a weight factor was applied (Table 11).

Criteria	Weight factor
Boundary Marking	3
Flooring	2
Roofing	1

Table 11 The criteria, their ranking and weight factor for Building Vulnerability

The importance of the criteria is connected with the level of influence the factors have on the island's building vulnerability and with the mitigation measures that may be taken. Low weighting was given to characteristics which communities can alter with minimum cost. These include roofing and flooring used in the buildings.

5.3.4.4 The Human Vulnerability (HV)

Once an assessment of the vulnerability of the building of the island and islands natural vulnerability had been undertaken, it was possible to assess the human vulnerability for the island.

The Human Vulnerability for the inhabited islands was calculated according to the following equation:

$$HV = IV \times BV \times P \qquad \textbf{(4)}$$

HV – Human Vulnerability

BV – Building Vulnerability

P – Population (standardised population of the island)

5.3.4.5 The Island Vulnerability Index (IVI)

The Island Vulnerability Index has been presented using a multi criteria evaluation method which depends on an island's natural vulnerability, island build environment vulnerability and human environment vulnerability as presented in equation 5.

$$\mathrm{IVI} = \mathrm{IV} + \mathrm{BV} + \mathrm{HV} \qquad \textbf{(5)}$$

The study was unable to determine the exact relation between the Island Vulnerability and islands natural vulnerability, building vulnerability and human vulnerability as this was beyond the scope of the study. However the study acknowledges that the island's vulnerability is a function of the island's natural vulnerability, building vulnerability and human vulnerability. Hence for the purpose of this study, an assumption was made that the island vulnerability index is as presented in Equation 5.

5.3.4.6 Presentation of the Findings

In disaster risk assessment, GIS technology is widely utilised (Singh, 2006). GIS is a system of computer hardware, software and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially referenced data for solving complex planning and management problems (Demers, 1999). One of the most important features of GIS is the manipulation and analysis of spatial and non spatial data. This capability of GIS has been used in this study for the data analysis and the presentation of the findings of the spatial information.

ArcView 3.2a was the GIS platform which was used in the study. The dataset which was converted to 'dbf4' using Microsoft Excel 2003 was used as the data input for the ArcView. Maps produced from ArcView as output were used to present the findings of the study which will be found in different section of this document. The Maps section of the Table of Content is a quick guide to find these maps within the text.

6 Research Findings

6.1 Demography of the Maldives

6.1.1 Distribution of Population across the Islands

In 2006, the total population of the Maldives, 298,968, was distributed across 198 islands. Kench et al. (2006) suggested that the small area of the Maldives makes these islands vulnerable to natural disasters such as predicted climate change and events such as the tsunami. Figure 32 shows the distribution of the populations against the area of the populated islands.

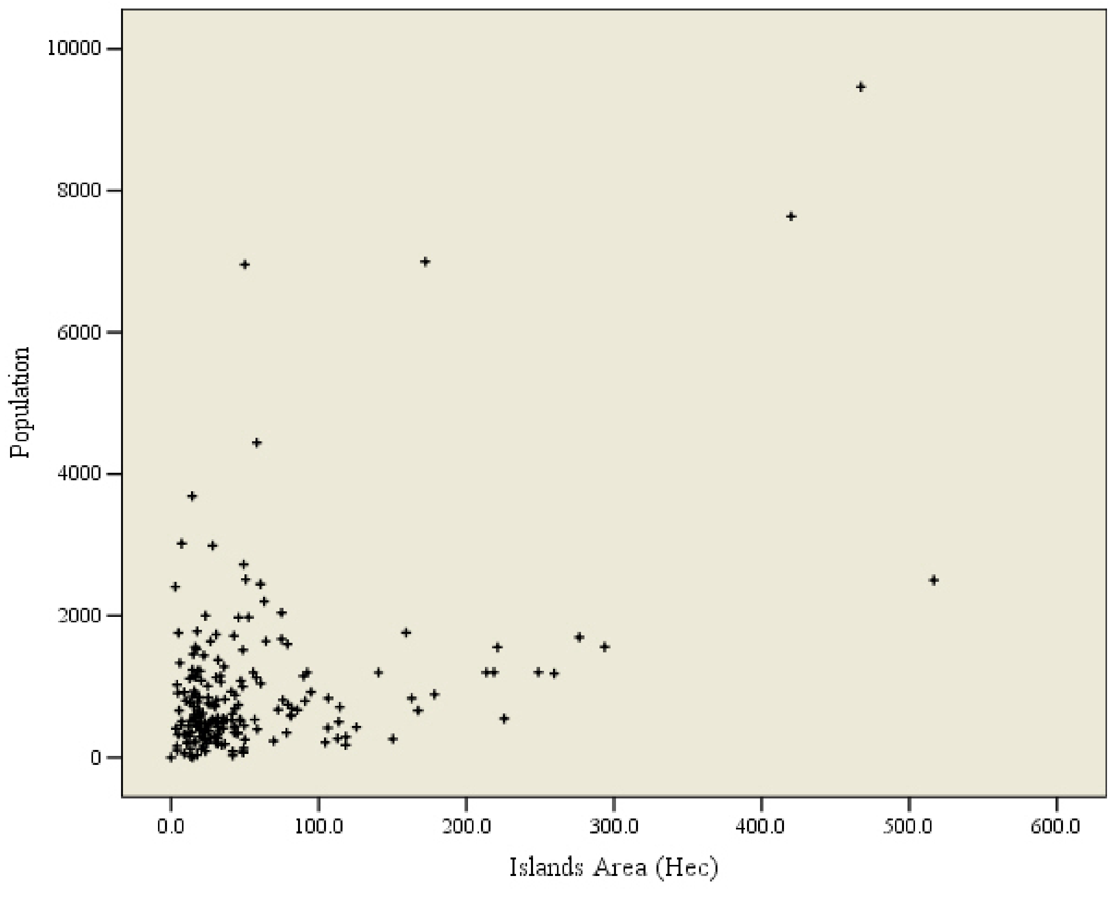


Figure 32: Distribution of the Population with respect to Island's Sizes

Figure 32 shows that a large number of inhabited islands are relatively small and have large populations. High population density on small islands exposes the population to disasters such as flooding caused by tsunami as the islands have less buffer zone to absorb the impacts of such disasters.

6.2 Geographic and Geomorphologic Findings

6.2.1 Geographic Distribution of the Islands in the Archipelago

The islands of the Maldives are geographically distributed across 26 natural atolls. Figure 33 shows the geographic distribution of the islands across the archipelago.

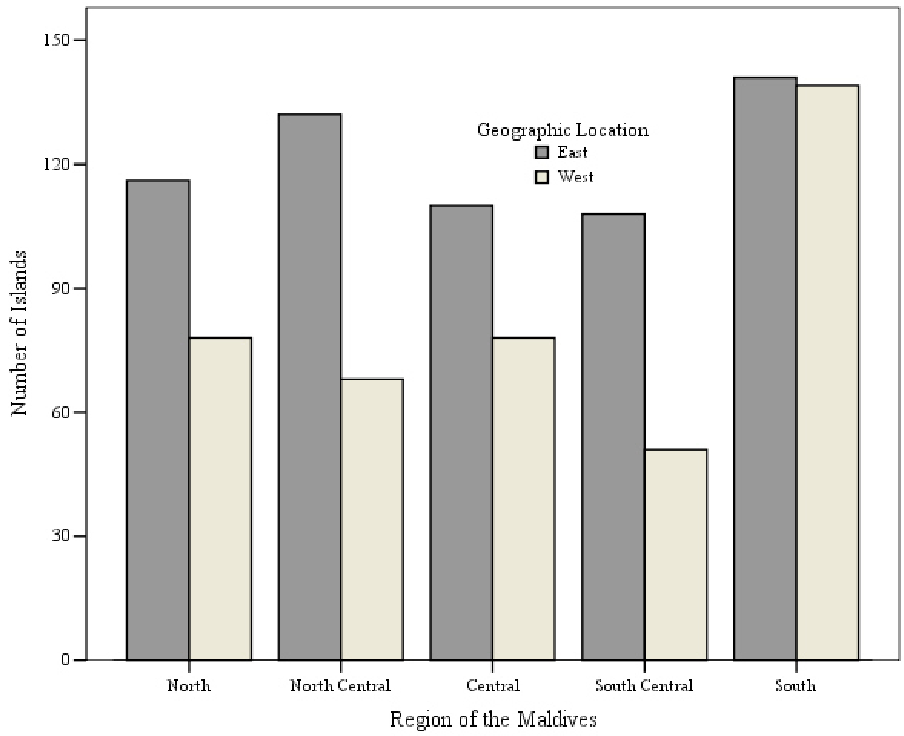


Figure 33: Geographic Distribution of the Islands in the Archipelago

It is also observed that the islands are geographically distributed dominantly on the eastern side of the country. 58.5% of the 1021 islands, scattered across 26 atolls, are located on the eastern side of the country. In all regions, more islands are located on the eastern side than on the western side of the country. Table 12 shows that 27% of the islands are located on the southern region of the Maldives while 52.7 % of the islands are located in the central regions of the country.

	Number of Islands	Percent
North	194	18.7
North Central	200	19.3
Central	188	18.1
South Central	159	15.3
South	280	27.0
	1,021	100.0

Table 12: Distribution of the Islands across the Regions

6.2.2 Location of Islands within the Atoll

The islands that are found in the atolls are distributed on the atoll rim and inside the rim. Figure 34 shows the distribution of the islands within the atolls of the Maldives. 435 islands are located in the eastern side of the island while 28.1 % and 28.4 % are located inside the atoll and at the western side of the atoll rim respectively.

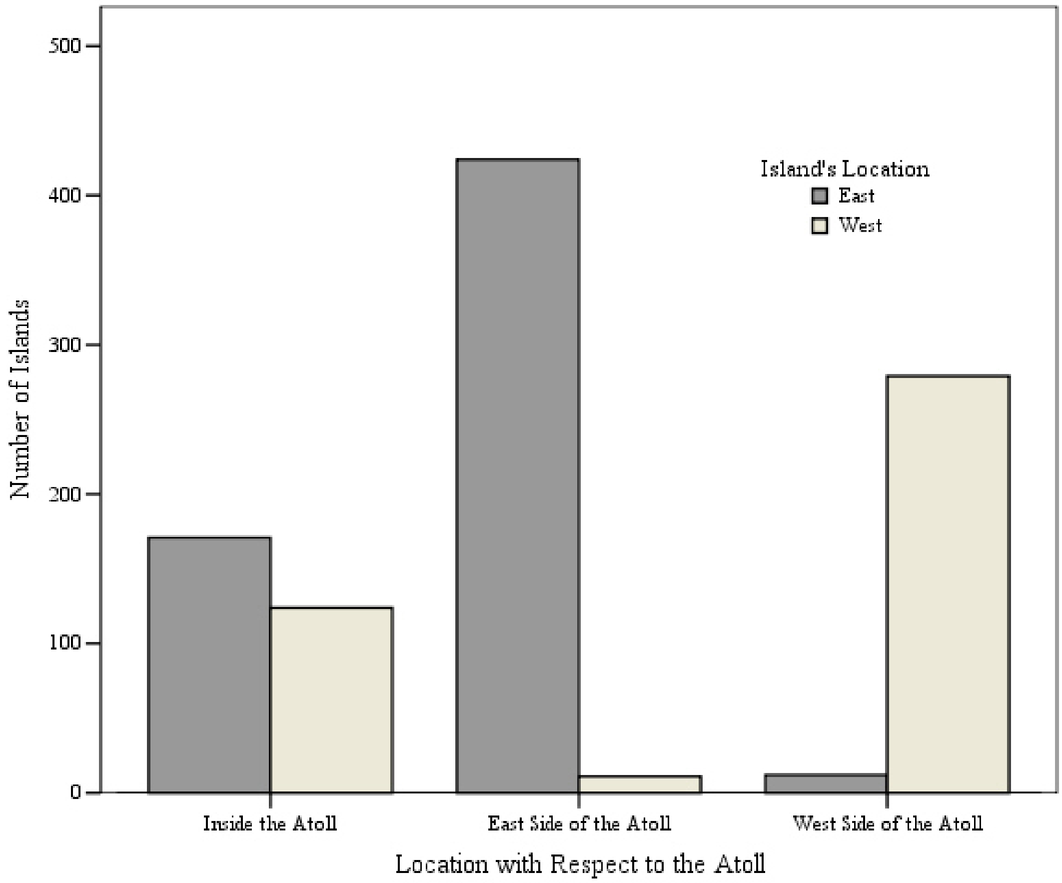


Figure 34: Island's Location within the Atoll

6.2.2.1 Inhabited Islands Location within the Atoll

The geographic distribution of inhabited islands have similar distribution as that of all islands which were presented in Figure 34. Most of the inhabited islands are located on the eastern side of the country on the eastern atoll rim.

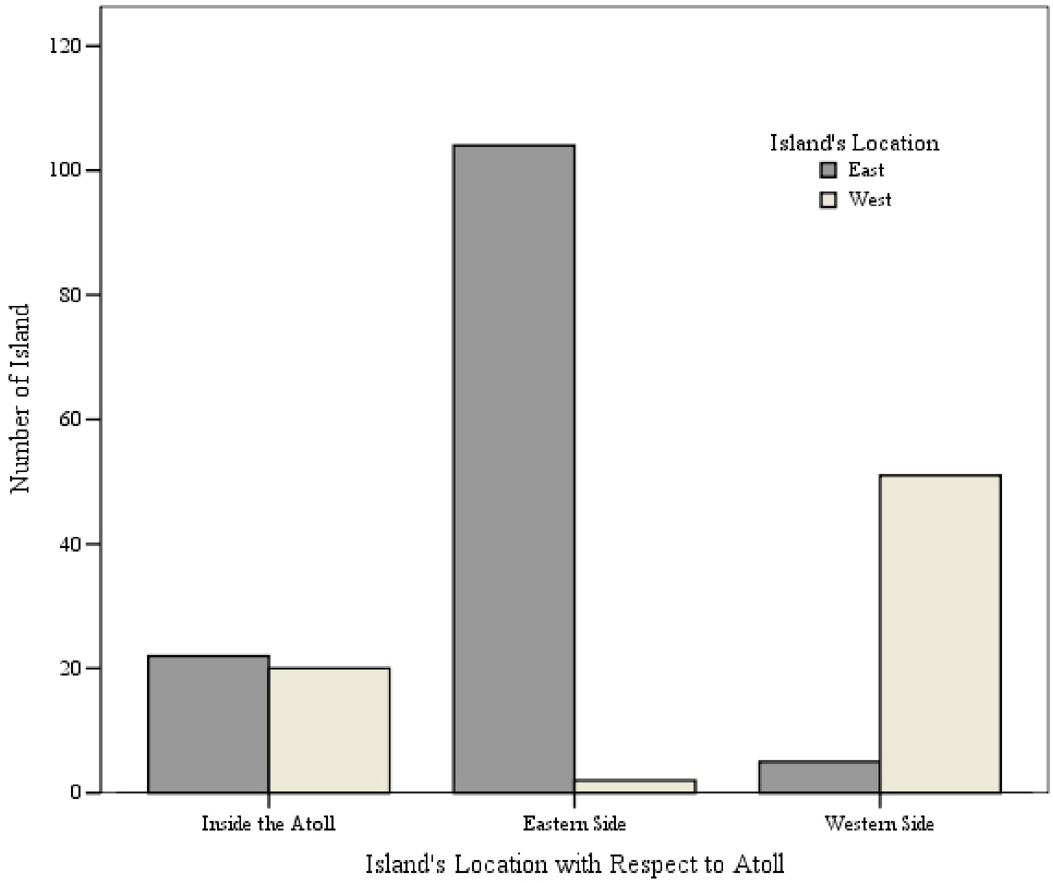


Figure 35: Inhabited Island's Location within the Atoll

6.2.3 Shape Distribution of Islands across the Archipelago

An important factor of the island's physical vulnerability is the shape of the island. The shape of the islands of the Maldives was categorised into 6 major shapes as outlined in Figure 36. Elongate and circular shape is most common in the Maldives which accounts for 71.0 % of the islands. Of these, elongated shapes are most common, accounting for 85.3 % and circular shaped island represents 14.7% of islands. The next most common shape, the bay shaped islands account for 12.6 %. Most of these elongated, circular and bay shaped islands are located on the eastern side of the country.

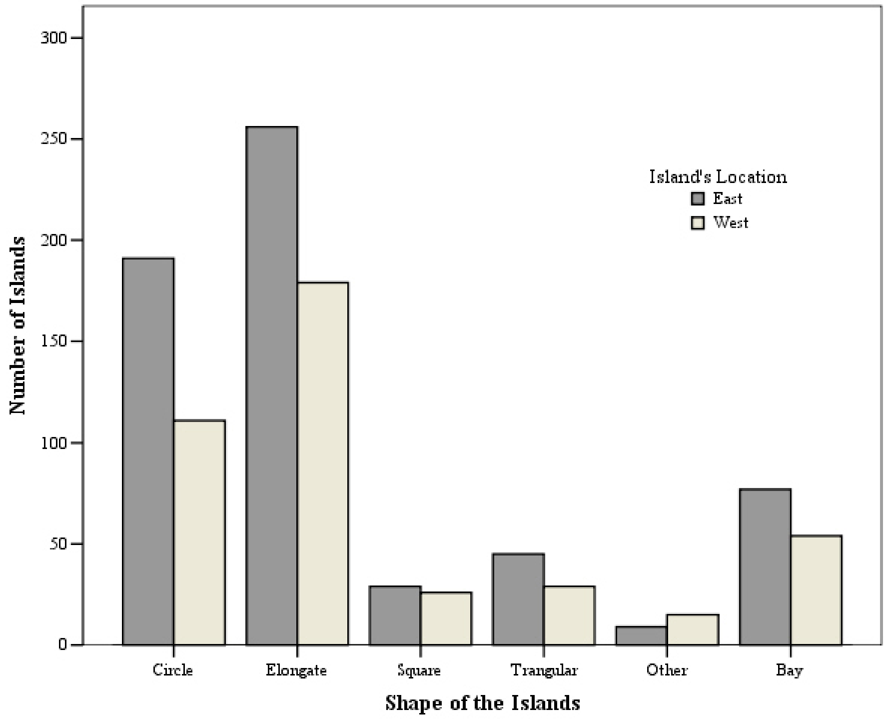


Figure 36: Island's Shape Distribution across the Archipelago

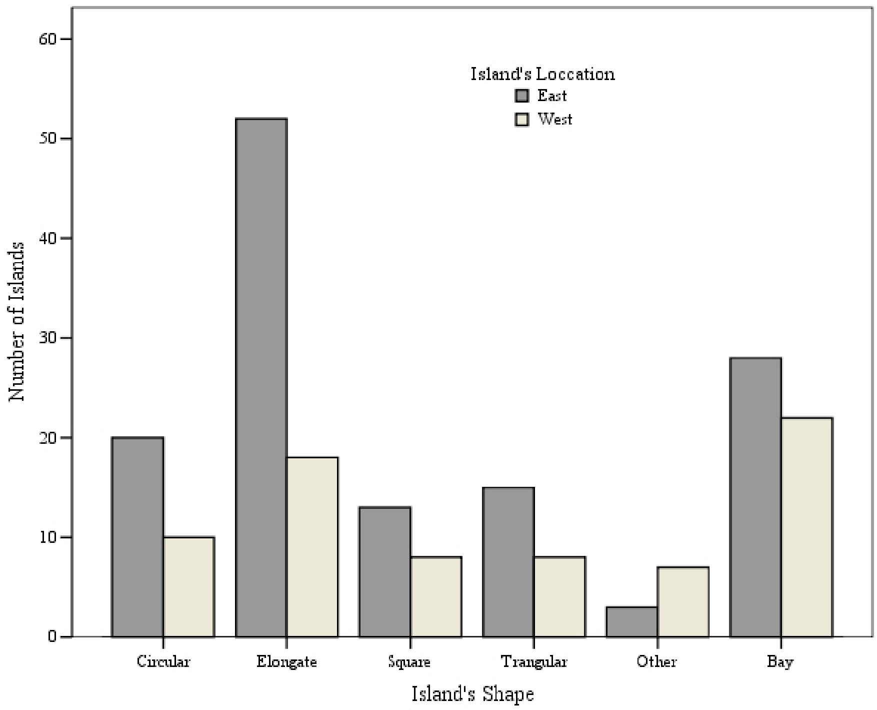


Figure 37: Inhabited Island's Shape Distribution

6.2.4 Orientation of the Inhabited Islands

An island's orientation is one of the factors which determine the island's vulnerability to flooding. The orientation of the islands were determined using topographic map of the Maldives using atlas of the Maldives (Godfrey, 2004). The orientation of the islands was catategorised into North – South, East – West, North East – South West and North West – South East.

According to the orientation classification, the most dominant orientation for the inhabited island was found to be the North East – South West direction. 67 inhabited islands have North East – South West orientation while 27% of inhabited islands have North West – South East orientation.

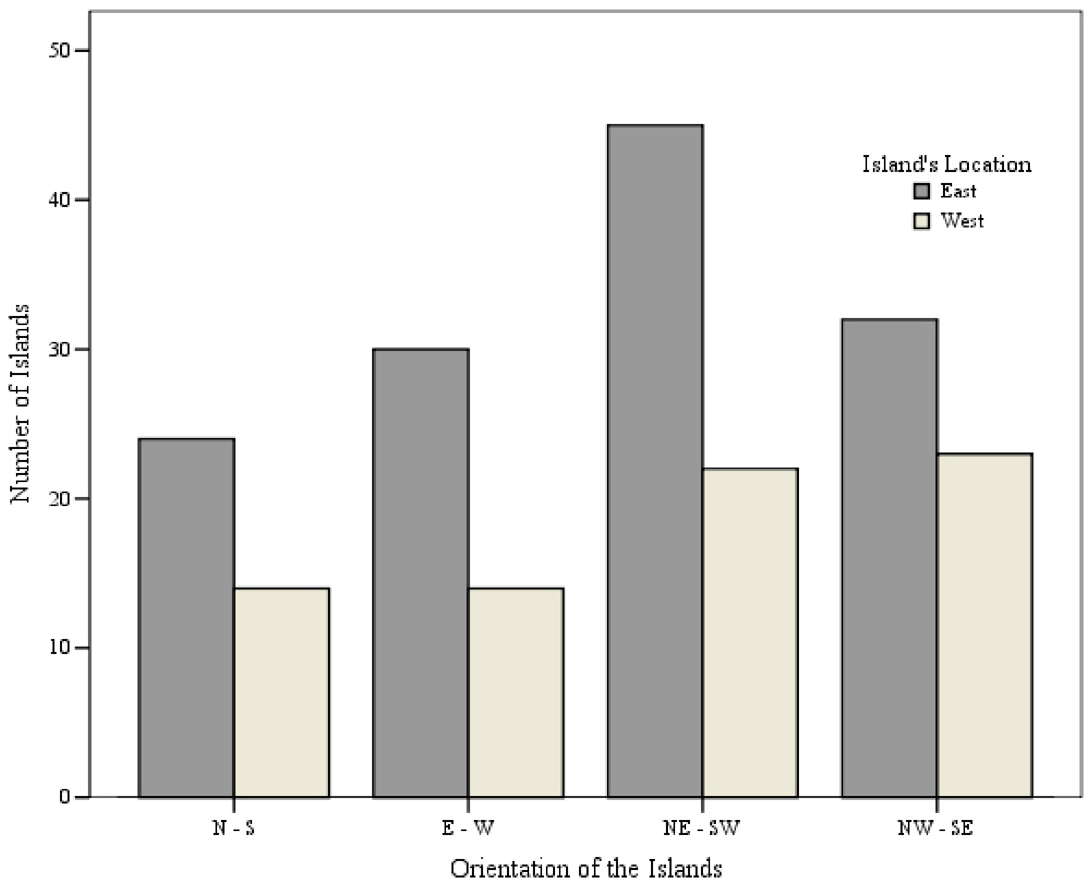


Figure 38: Orientation of Inhabited Islands

6.2.5 Distribution of the Lakes across the Island

Some of the islands of the Maldives have in-land lakes. Sometimes these lakes are referred to as wetlands. Figure 39 shows the distribution of the lakes in the islands of the Maldives. 31 islands have inland-lakes and the mean area of the lakes is 6.62 hectares. UNEP (2005) pointed out that inland water lakes played a role to minimise the impact of the tsunami on the terrestrial environment of the island by providing a natural buffer to absorb the sudden influx of the large volume of salt water on the island by the tsunami.

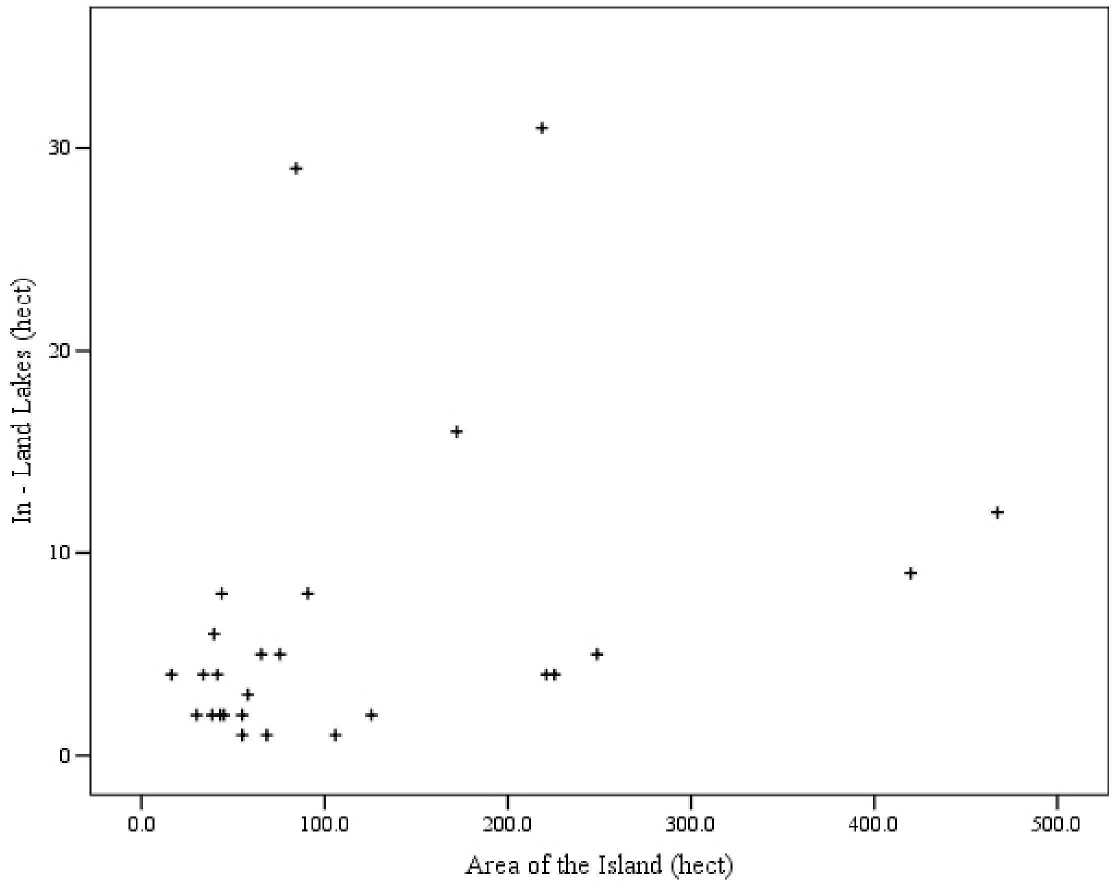


Figure 39: Distribution of the Lakes across the Island

6.3 *Impact of Tsunami on the Islands of the Maldives*

6.3.1 Impact on Beaches

The Indian Ocean Tsunami of December 2004 had significant impacts on the beaches of the Maldives islands. The beaches of 92 islands were impacted by the tsunami. Figure 40 shows the level of impact on these islands.

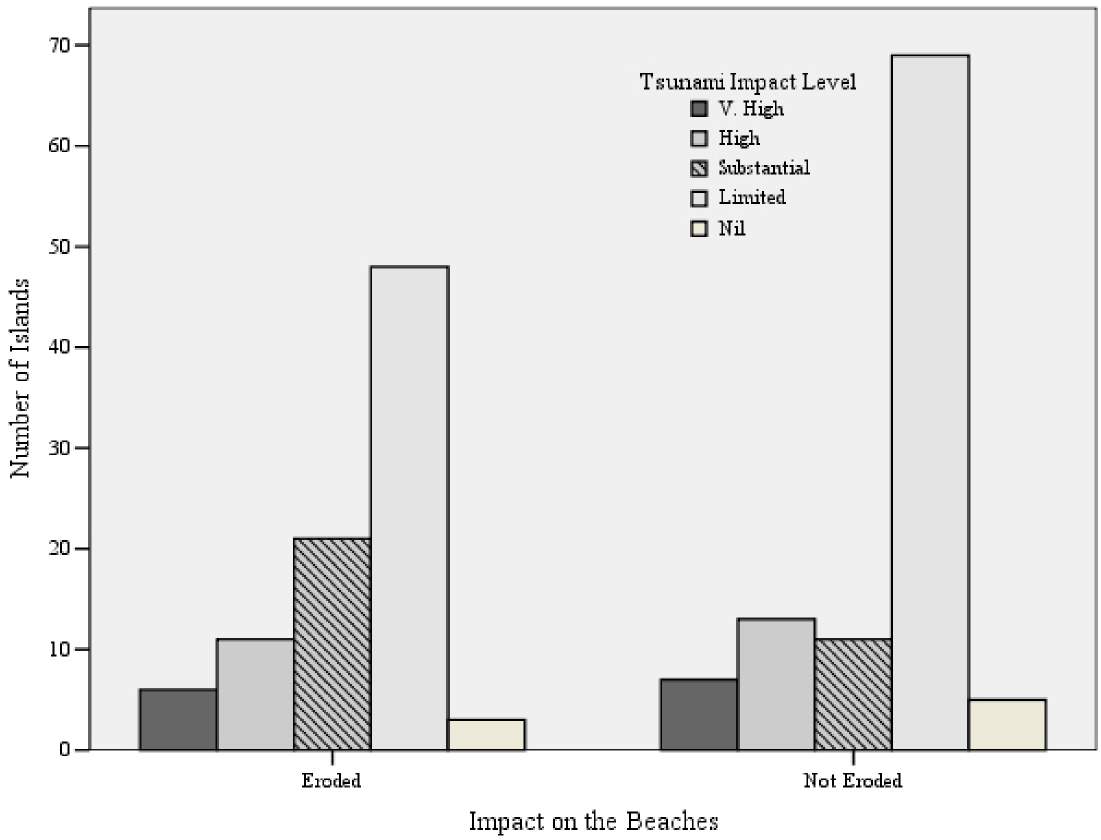


Figure 40: Tsunami Impact on Island's Beach

6.3.2 Influence of Island's Shape and Location on Level of Tsunami Impact

The islands which were impacted, very highly, highly and substantially, by the tsunami of December 2004 were used to find a relationship between the level of impact and island's shape and its location within the atoll. Figure 41 shows the number of islands which were impacted as functions of their shape and location within the atoll.

Figure 41 shows that most of the impacted islands were located on eastern side of the atoll while the islands which were found inside the atolls were relatively not impacted. The circular islands which were found in the centre of the atoll were safe compared to the circular islands which were on western and eastern side of the island. The islands which were located in eastern side of the islands were much more exposed and impacted by the tsunami. Figure 41 also shows that the elongate and bay shaped islands on eastern side of the atoll were much more vulnerable to tsunami and were impacted by tsunami.

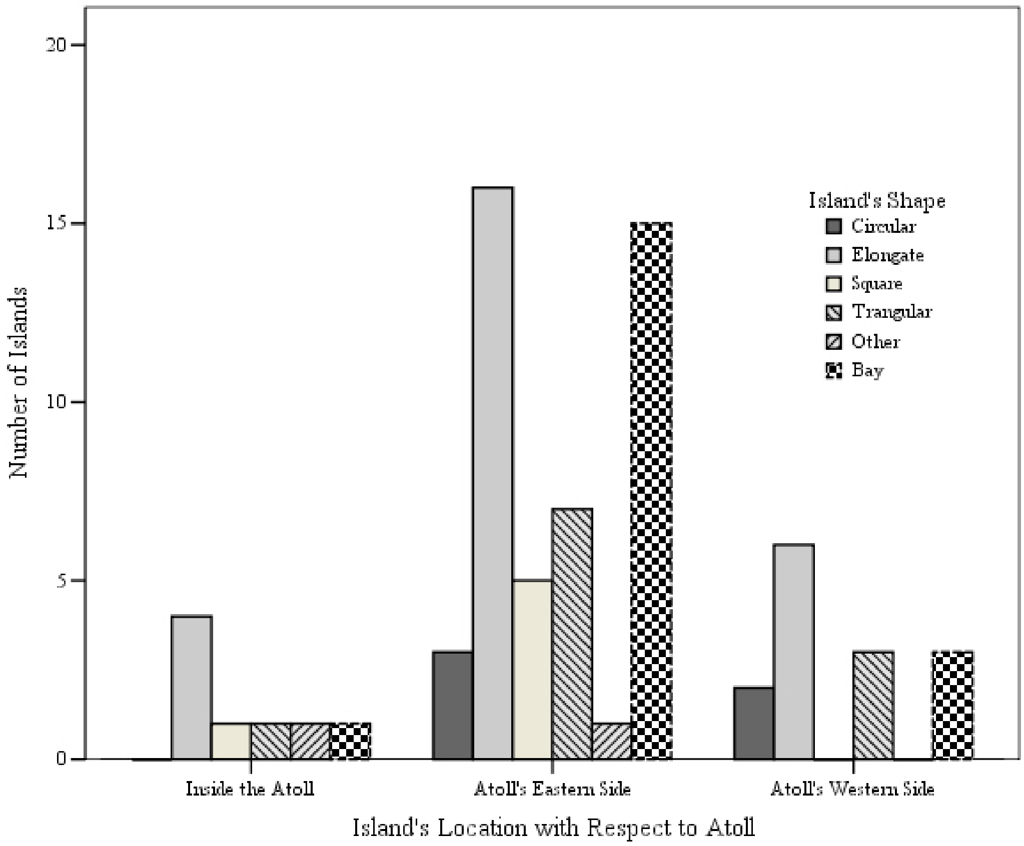


Figure 41: Influence of Island's Shape and Location on the Level of Tsunami Impact on Island's

6.4 Influence of Island's Shape and Level of Shadow on Tsunami Impact

The geographic distribution of the islands and reefs in the Maldives make some islands sheltered by the shadow from other islands and reefs. The islands which were impacted, very highly, highly and substantially by the tsunami of December 2004 were used to analyse to find a relationship between the level of impact and island's shape and level of shadow the island had within the atoll. Figure 42 gives an account of this analysis.

Most of the impacted islands were exposed from the eastern side or were fully exposed. 23% of the impacted islands were shadowed from west but exposed from east where tsunami waves approached the islands. 52.5 % of the impacted islands were not sheltered from east or west and were fully exposed to the tsunami waves which approached the islands from eastern side of the Maldives.

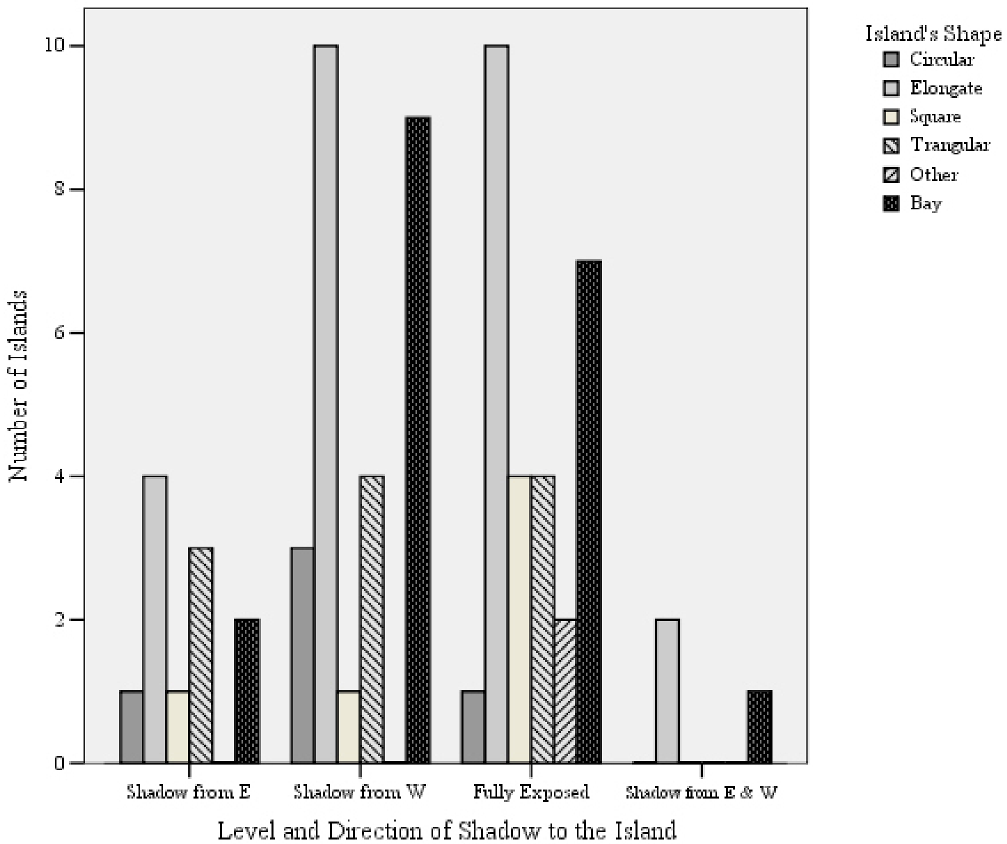


Figure 42: Influence of Island's Shape and Level of Shadow on Tsunami Impact on Islands

Figure 42 shows that the shapes of the islands have an influence on the level of tsunami impact on the islands. Out of the 69 islands which were significantly impacted, 26 islands were elongated shape islands and 27.5 % represents bay shape islands.

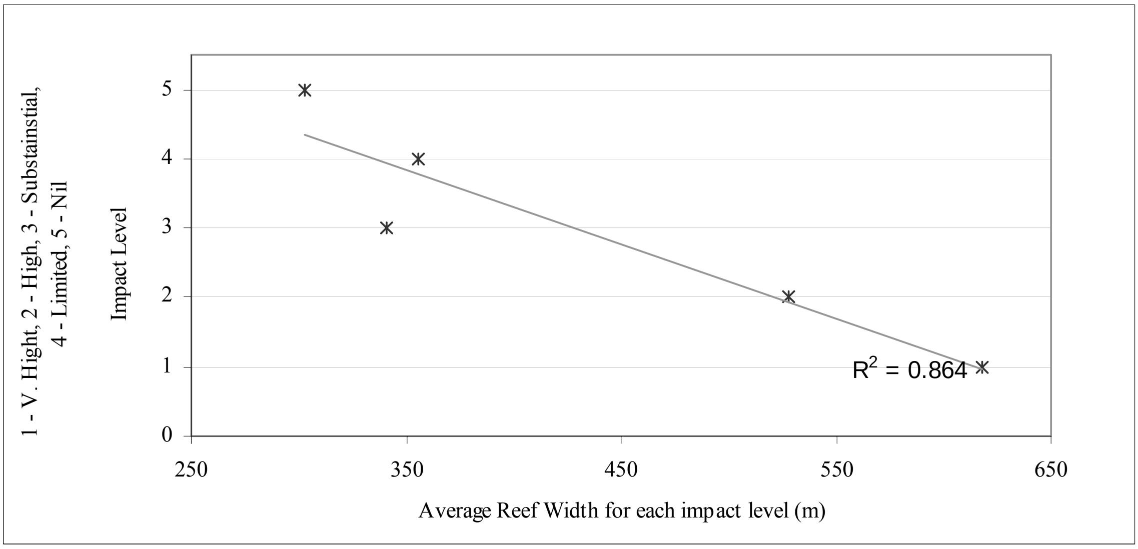


Figure 43: Influence of the island's house reef width on Tsunami Impact on Islands

Figure 43 shows the relationship between reef width and the level of impact on tsunami impacted islands. According to the plot, the level of impact shows a linear relationship with a correlation of 86 percent with respect to the reef width. Figure 43 also indicates that an increase in the width of the reef flat would result in higher impact level (ie higher inundation and possibly higher run-up of tsunami waves).

The way reef flats dissipate energy can be explained by the tsunami's wave length and the sudden change in depth. Because the wavelength is much longer compared to the amplitude, when the crest is transmitted onto the reef flat, a significant part of the wave crest would still remain in the deep ocean. The part of the crest that has been transmitted onto the reef flat slows down considerably, but the part in the deep ocean moving very fast continues to push into the reef flat. This causes water to pile up in front of the island. Therefore it is probable that if the reef flat is wider, it provides a bigger area for the water to pile up and increase in height causing higher inundation.

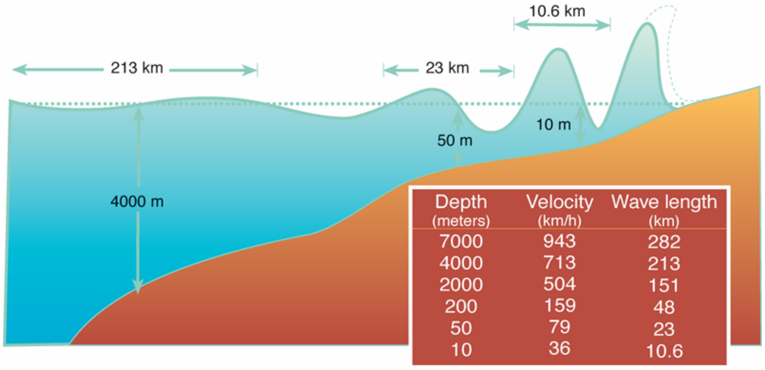


Figure 44: Tsunami Speed is reduced in shallow water as wave height increases rapidly (reproduced from IOC)

6.4.1 Size of Islands Impacted by Tsunami

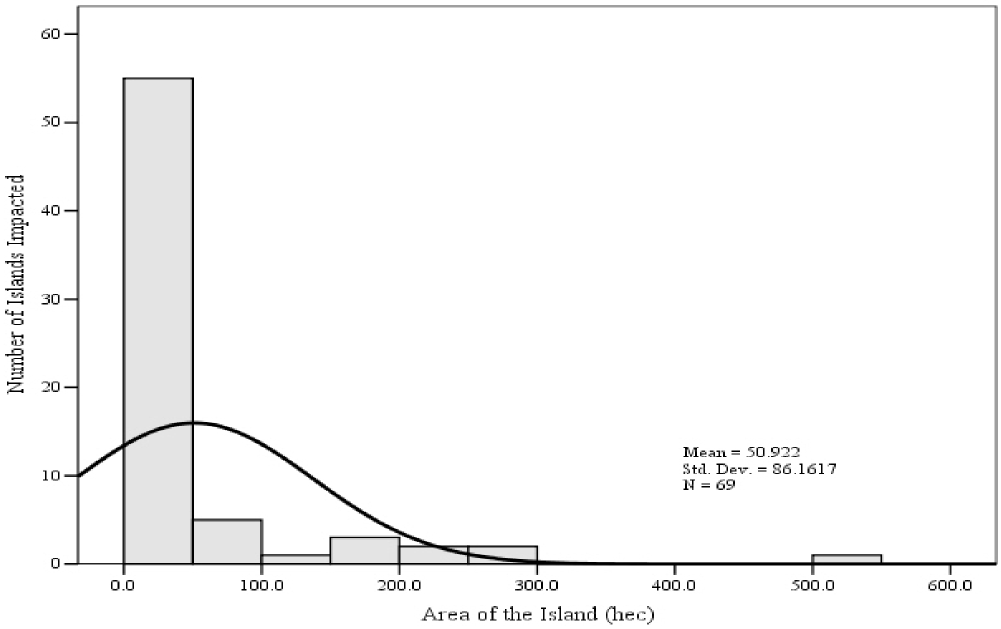


Figure 45: Distribution of Islands Impact and the Island's Area

Figure 45 shows the size distribution of the tsunami impacted islands. The average area of the impacted islands was 50.92 hectares; however, 79.7% of the impacted islands had an area less than 50 hectares. Islands which have an island area less than 50 hectares are more vulnerable compared with bigger islands.

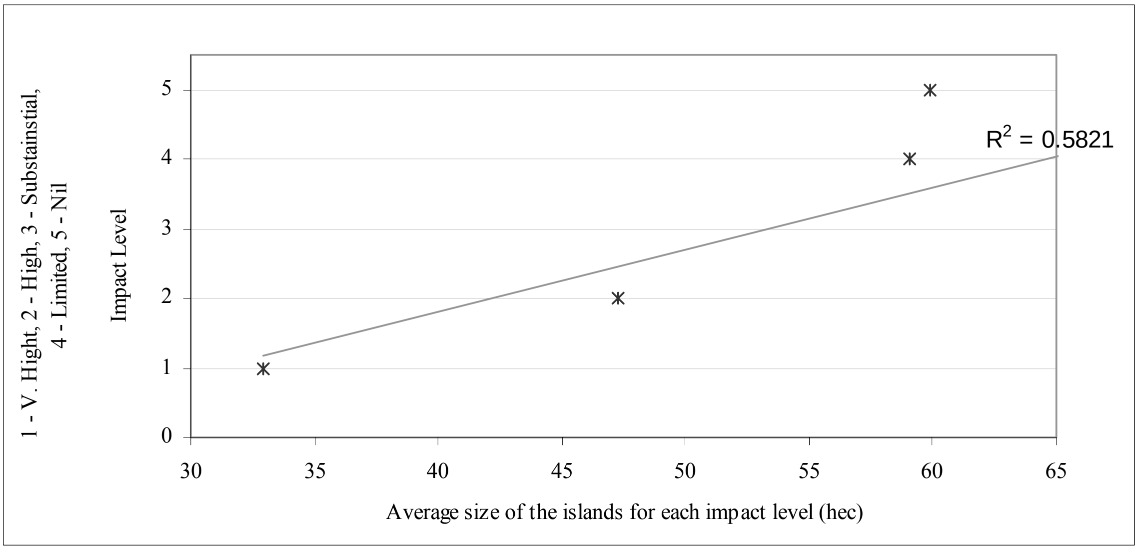


Figure 46: Influence of the Island's Size on Tsunami Impact Level

The impact level against the island size was analysed to see whether a correlation could be established (see Figure 46). The correlation calculated for this relationship is poor because the impact level depends on many other factors as descried previously. However, the plot indicates that an increase in the size of the island would result in a lower impact level (ie lower inundation and possibly higher run-up from tsunami waves approaching the island).

6.5 *Island Vulnerability for Tsunami*

The vulnerability of islands to impacts of tsunami was assessed for the inhabited islands based on the methodology as described in the methodology section in 5.3.4.2. This section presents the findings of the islands' natural vulnerability, building vulnerability and human vulnerability.

6.5.1 Island Natural Vulnerability

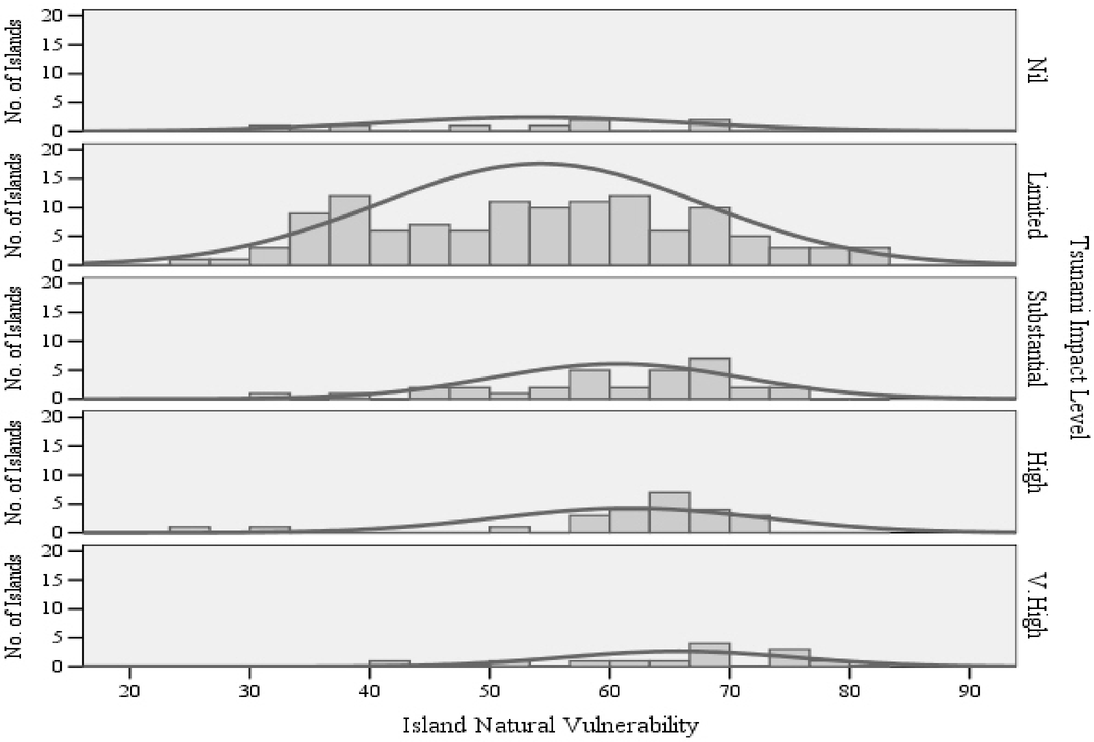


Figure 47: Islands Natural Vulnerability against the tsunami Impact level

The Island Natural Vulnerability to tsunami has been determined using Equation 2. Figure 47 presents the relationship between the islands' natural vulnerability and the tsunami impact level, which was observed following the Indian Ocean Tsunami on December 2004. Figure 47 shows that Island Natural Vulnerability when calculated using Equation 2 can simulate Tsunami Impact Level (ie higher the Island Natural Vulnerability, the higher the Tsunami Impact Level). Though this was not a good correlation, it has been determined after undertaking a sensitivity analysis of the weighting which was applied for different factors which determines the Island Natural Vulnerability

Tsunami Impact Level	Description	Island Natural Vulnerability				
		Number	Min	Max	Mean	St Deviation
1	V. High	13	43	77	65.8	9.8
2	High	24	26	73	61.7	11.2
3	Sustaintial	32	33	75	60.6	10.4
4	Limited	119	26	83	54.2	13.5
5	Nil	8	33	69	53.6	13.0

Table 13: Analysis of the calculated Island Natural Vulnerability against the Observed Tsunami Impact Level

These findings show a need to develop a classification of the island's natural vulnerability. Hence, an analysis of Figure 47 was undertaken to establish boundaries where islands natural vulnerability classification could be developed. Table 13 presents such an analysis where the island vulnerability is calculated against the observed tsunami impact level. Following the analysis, the island natural vulnerability classification presented in Table 14 was developed. A simple approach for classification was adopted keeping mind that the results of this study could be used as a tool by urban planners or any other professions for their initial assessments. Detailed assessment would follow where site specific data and information would be used in more sophisticated models to understand the site specific characteristics of the local environment.

Island Natural Vulnerability	Details	Island Natural Vulnerability (Description)
1	if calculated score ≥ 74	Very High
2	if calculated score is between 62 - 73	High
3	if calculated score is between 50 - 61	Moderate
4	if calculated score is between 38 - 49	Low
5	if calculated score ≤ 37	Very Low

Table 14: Island Natural Vulnerability Classification used in the study

Based on the classification of the Island Natural Vulnerability on Table 14, the inhabited islands were classified. Figure 48 shows the distribution of the natural island vulnerability across the archipelago of the Maldives.

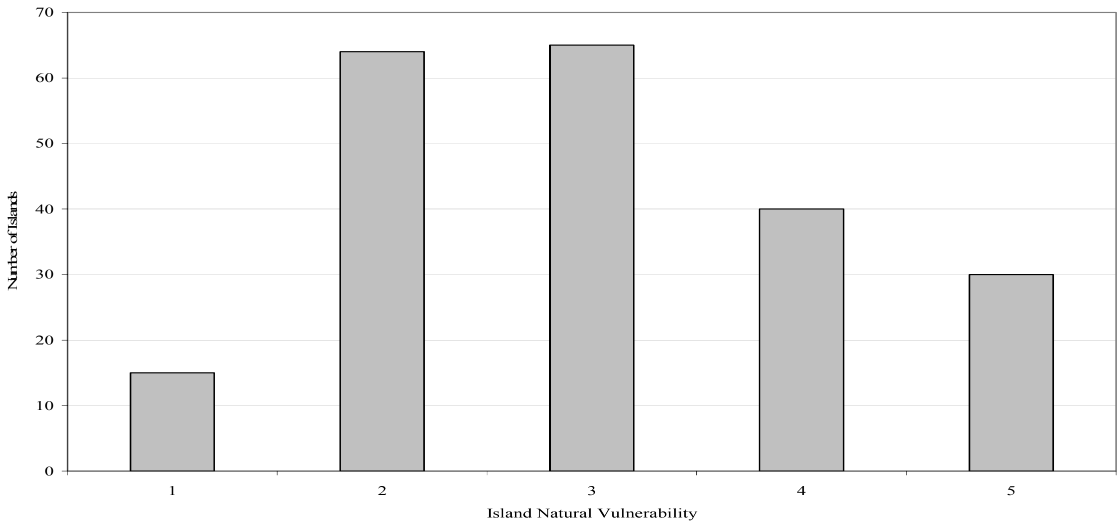


Figure 48: Distribution of Island Natural Vulnerability across the Inhabited Islands

6.5.2 Building Vulnerability

The building vulnerability classification presented in Table 15 was developed using the similar approach as was adopted for the island vulnerability classification which is described in section 6.5.1.

Building Vulnerability	Details	Buildingl\ Vulnerability (Description)
1	if calculated score ≥ 16	Very High
2	if calculated score is between 12 - 16	High
3	if calculated score is between 8 - 12	Moderate
4	if calculated score is between 4 - 8	Low
5	if calculated score ≤ 4	Very Low

Table 15: Building Vulnerability Classification adopted for the study

The Building Vulnerability assessment shows that buildings on the islands are vulnerable to the impacts of tsunami and similar kind of episodic flooding. In 5 islands, the buildings had very high vulnerability for damage from a tsunami flooding while 14 islands had very low Building Vulnerability as presented in Table 16.

BUILDING VULNERABILITY			
Index	**Description**	**Number of Islands**	**%**
5	V.High	5	2.45
4	High	30	14.71
3	Moderate	77	37.75
2	Low	71	34.80
1	V. Low	14	6.86

Table 16 Distribution of Building Vulnerability across the inhabited islands of the Maldives

6.5.3 Human Vulnerability

The Human Vulnerability for the inhabited islands is calculated according to the following Equation 4:

The human vulnerability classification presented in Table 17 was developed using the similar approach as was adopted for the island vulnerability classification which is described in section 6.5.1.

Population Vulnerability	Details	Building Vulnerability (Description)
1	if calculated score ≥ 1.90	Very High
2	if calculated score is between 1.00 - 1.90	High
3	if calculated score is between 0.60 - 1.00	Moderate
4	if calculated score is between 0.12 - 1.00	Low
5	if calculated score ≤ 0.12	Very Low

Table 17: Human Vulnerability classification adopted for the study

Table 18 shows the distribution of the human vulnerability across the islands of the Maldives. 7 islands are classified as having a very high Human Vulnerability to impact from tsunami, and 51 islands are ranked as having a very low Human Vulnerability to impact from tsunami.

POPULATION VULNERABILITY			
Index	Description	Number of Islands	%
5	V.High	7	3.43
4	High	15	7.35
3	Moderate	24	11.76
2	Low	107	52.45
1	V. Low	51	25.00

Table 18 Distribution of Human Vulnerability across the inhabited islands of the Maldives

6.5.4 Island Vulnerability Index

The Island Vulnerability Index has been presented using a multi criteria evaluation method which depends on the island's Natural Vulnerability, Built Environment Vulnerability and Human Environment Vulnerability as presented in Equation 5. Island Vulnerability Index was calculated for all the inhabited/impacted islands.

6.5.4.1 Building Vulnerability

The Building Vulnerability of the inhabited islands was assessed against the island's vulnerability index. Figure 49 shows the relationship between the building vulnerability against the island vulnerability index. The Building Vulnerability against the Island Vulnerability Index for inhabited islands shows a weak linear correlation of 12 percent. It is seen that the building vulnerability is less influenced by the island vulnerability index. A large number of less vulnerable islands show a low building vulnerability.

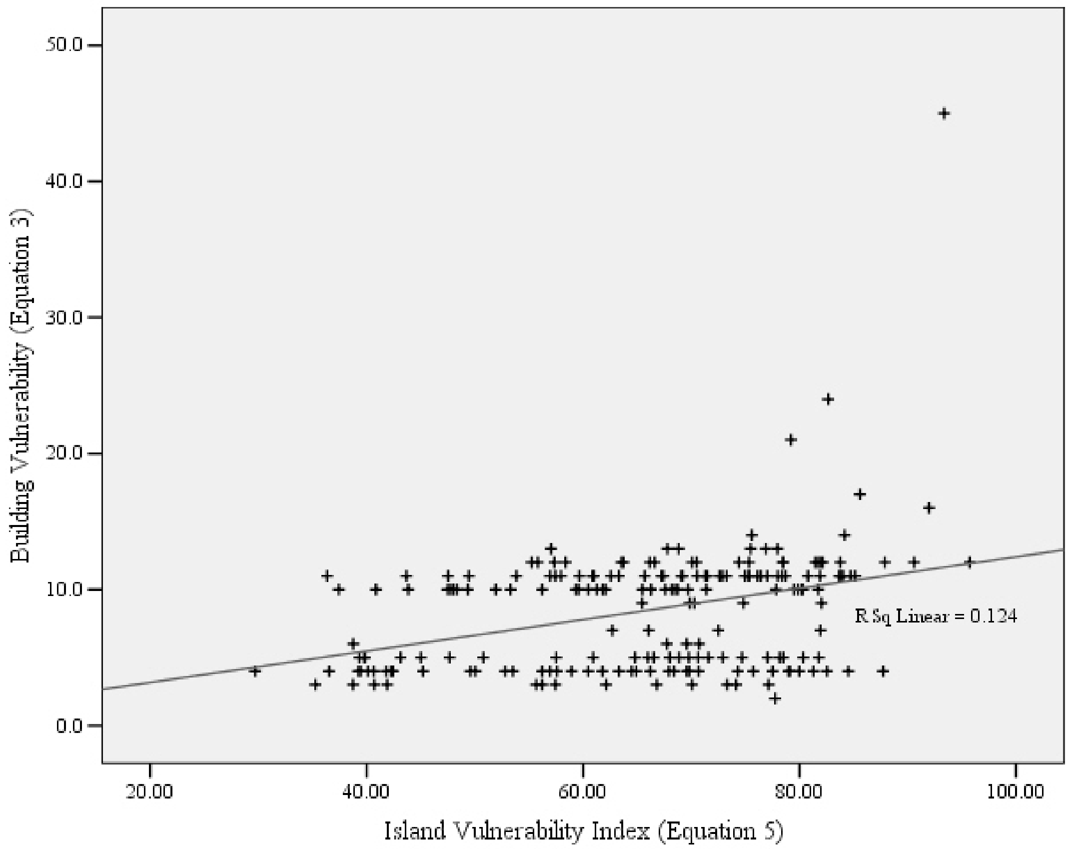


Figure 49: Building Vulnerability of the Inhabited Islands

6.5.4.2 Human Vulnerability

The Human Vulnerability of the inhabited islands was assessed against the island's vulnerability index (Figure 50) The Human Vulnerability against the Island Vulnerability Index for inhabited island shows a very weak linear correlation of less than one percent. It is seen that the human vulnerability is influenced by the island vulnerability index, to some degree, when human vulnerability is low.

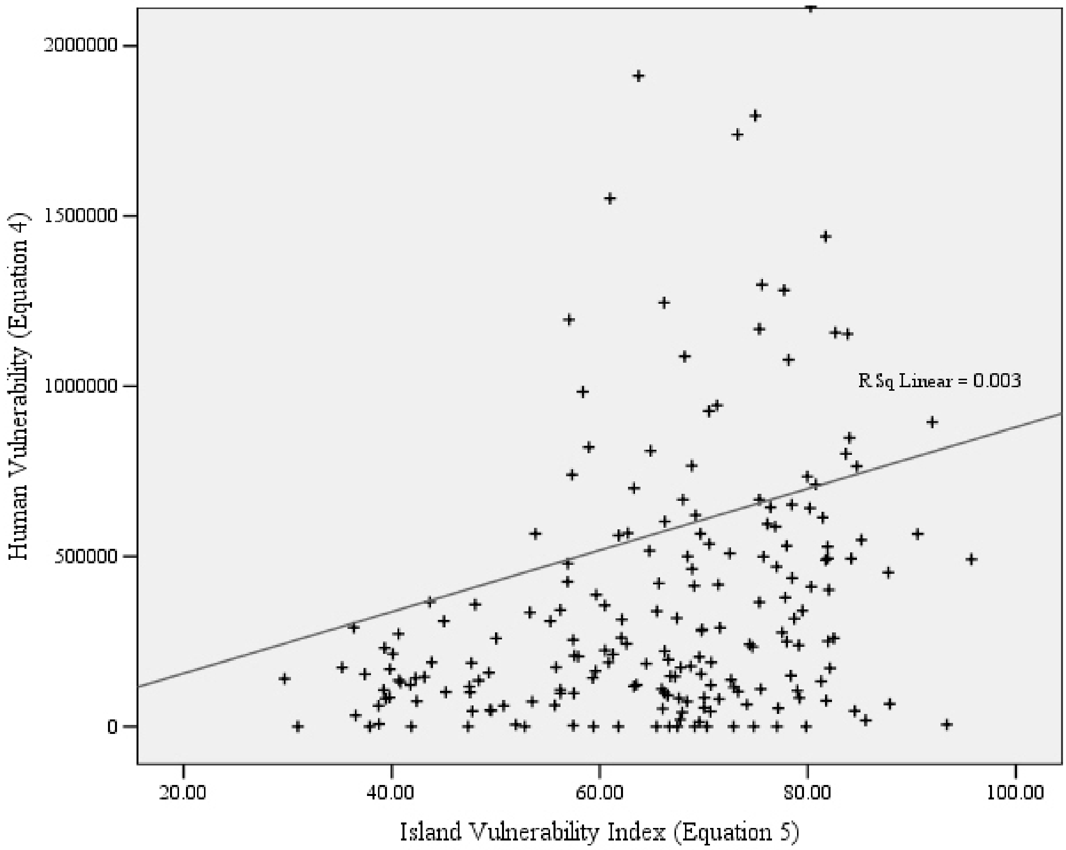


Figure 50: Human Vulnerability of the Inhabited Islands

6.5.4.3 Island's Natural Vulnerability

The Island's Natural Vulnerability of the inhabited islands was assessed against the island's vulnerability index (Figure 51). It was believed that that the island vulnerability index would be strongly influenced by the island's natural vulnerability (Papathoma et al., 2003). It is seen from Figure 51, that this assumption is true. The Island Natural Vulnerability against the Island Vulnerability Index on inhabited island show a strong linear correlation of 89 percent.

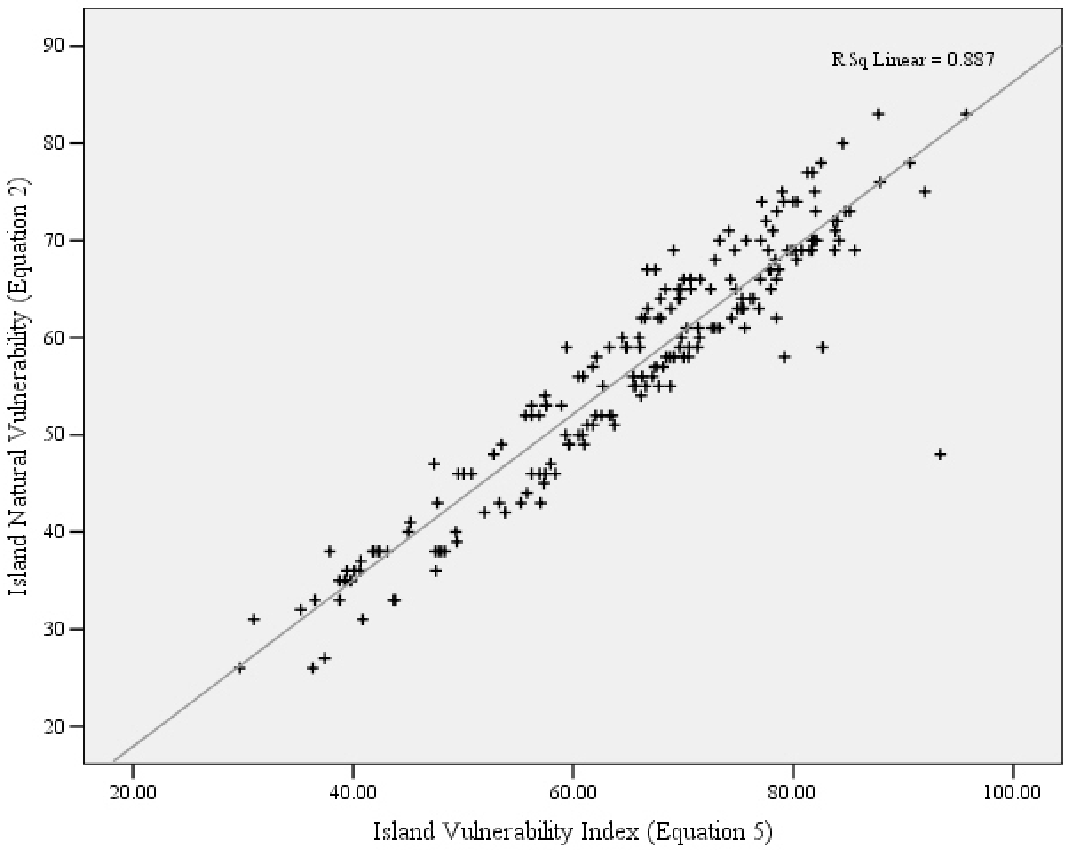


Figure 51: Islands Natural Vulnerability of the Inhabited Islands

6.5.5 Vulnerable Islands for Tsunami

The findings of this study show that the island vulnerability to tsunami is related to the islands natural vulnerability, building vulnerability of the island and the human vulnerability of the island. The building vulnerability and human vulnerability are factors over which there can be policy control, and interventions could be taken to reduce these vulnerabilities. The natural vulnerability of the islands is a factor over which there is less human control, other than to move the population of those islands to less vulnerable islands. Hence the island vulnerability for the tsunami is determined for all islands to identify the most vulnerable islands in the Maldives. Figure 52 shows the distribution of the islands classified according to its natural vulnerability. 15 inhabited islands and 109 uninhabited islands are classified as very highly vulnerable to tsunami given its natural characteristics. However, based on islands' natural characteristics 20 islands which are inhabited and 27 uninhabited islands are classified as islands which have very low vulnerability to disaster such as tsunami.

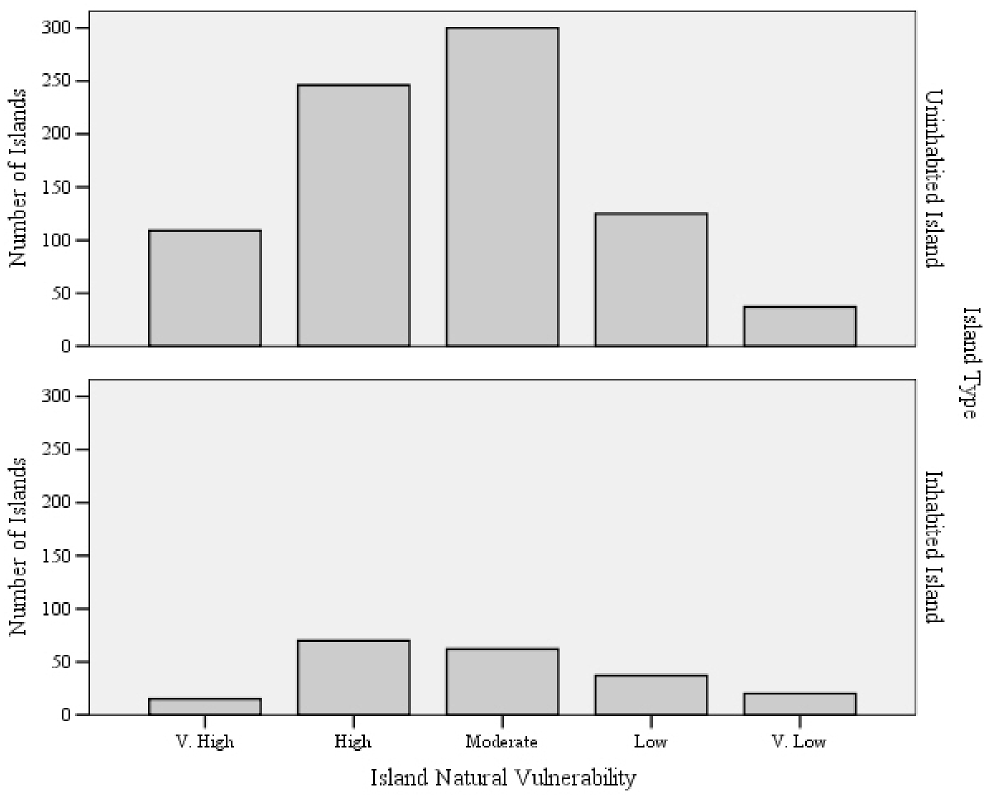


Figure 52: Island Natural Vulnerability of all islands in the Maldives

6.5.5.1 Spatial Distribution of the Vulnerable Islands

The spatial distribution of the vulnerable islands has been mapped using Arcview GIS platform and has been presented in Figure 53, Figure 54, Figure 55, Figure 56, Figure 57, Figure 58 & Figure 59. The islands marked on these maps are islands that have been proposed as safer islands in the Safer Island Development Programme.

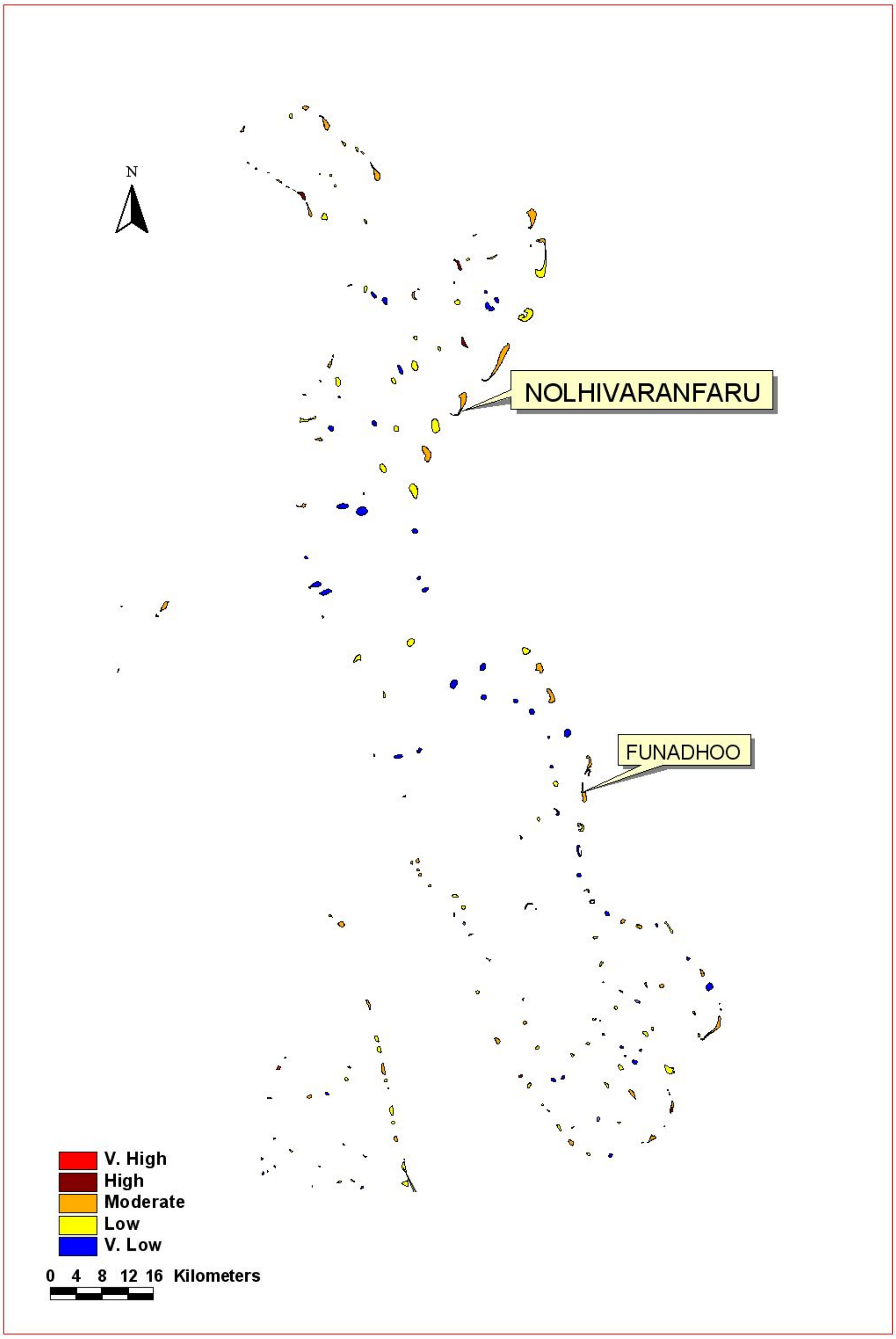


Figure 53; Island Natural Vulnerability of the Islands in the Region 1

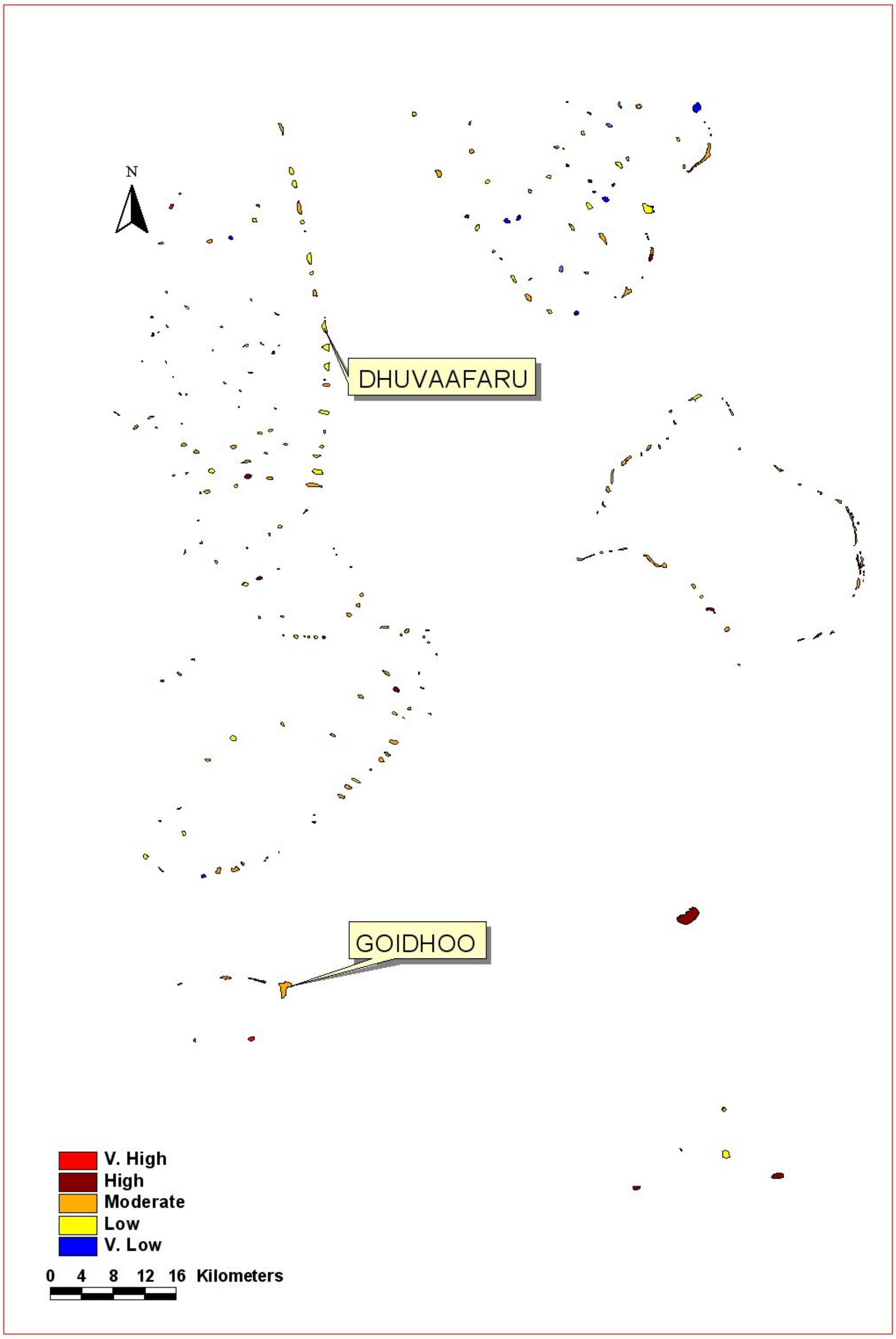


Figure 54; Island Natural Vulnerability of the Islands in the Region 2

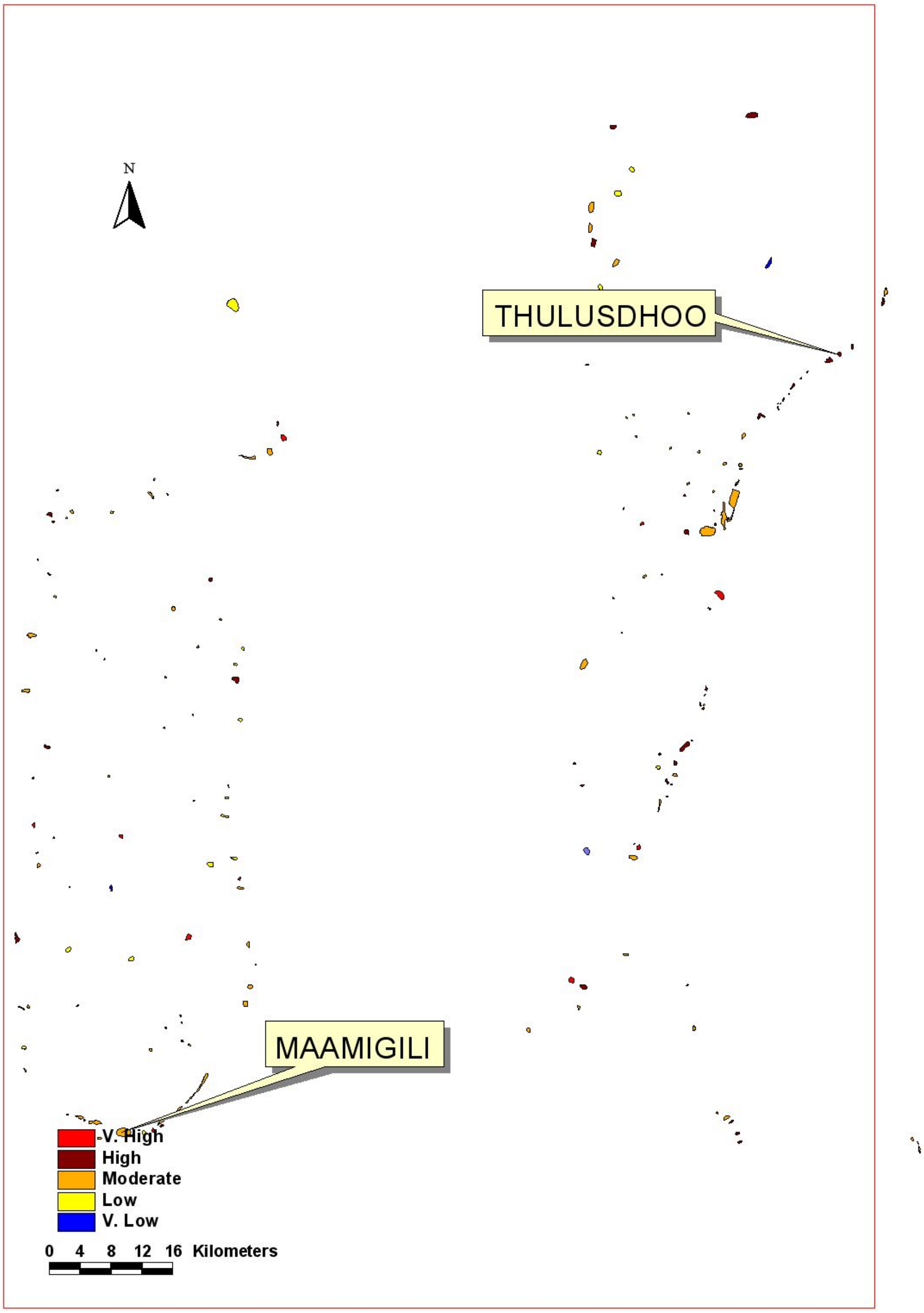


Figure 55; Island Natural Vulnerability of the Islands in the Region 3

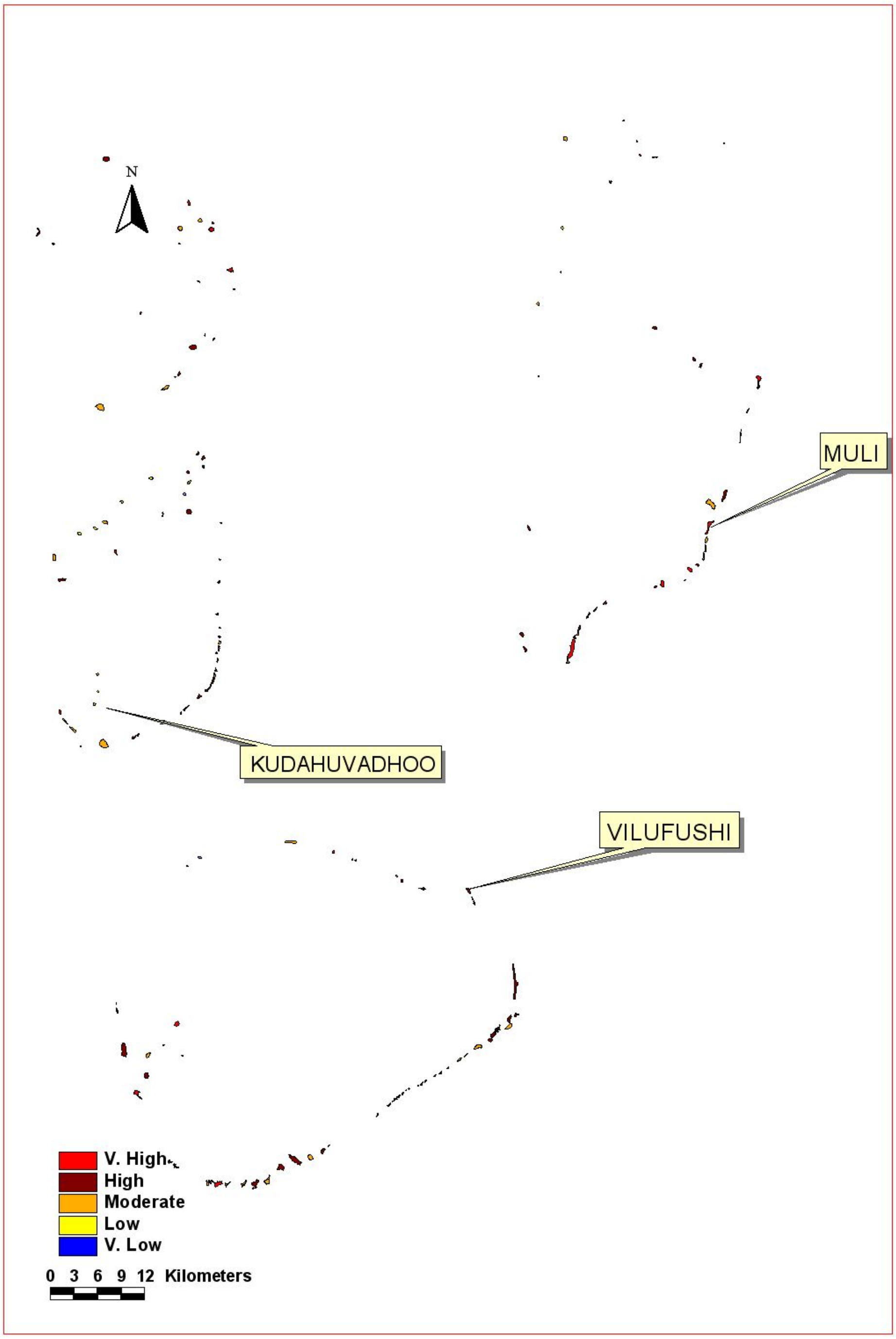


Figure 56; Island Natural Vulnerability of the Islands in the Region 4

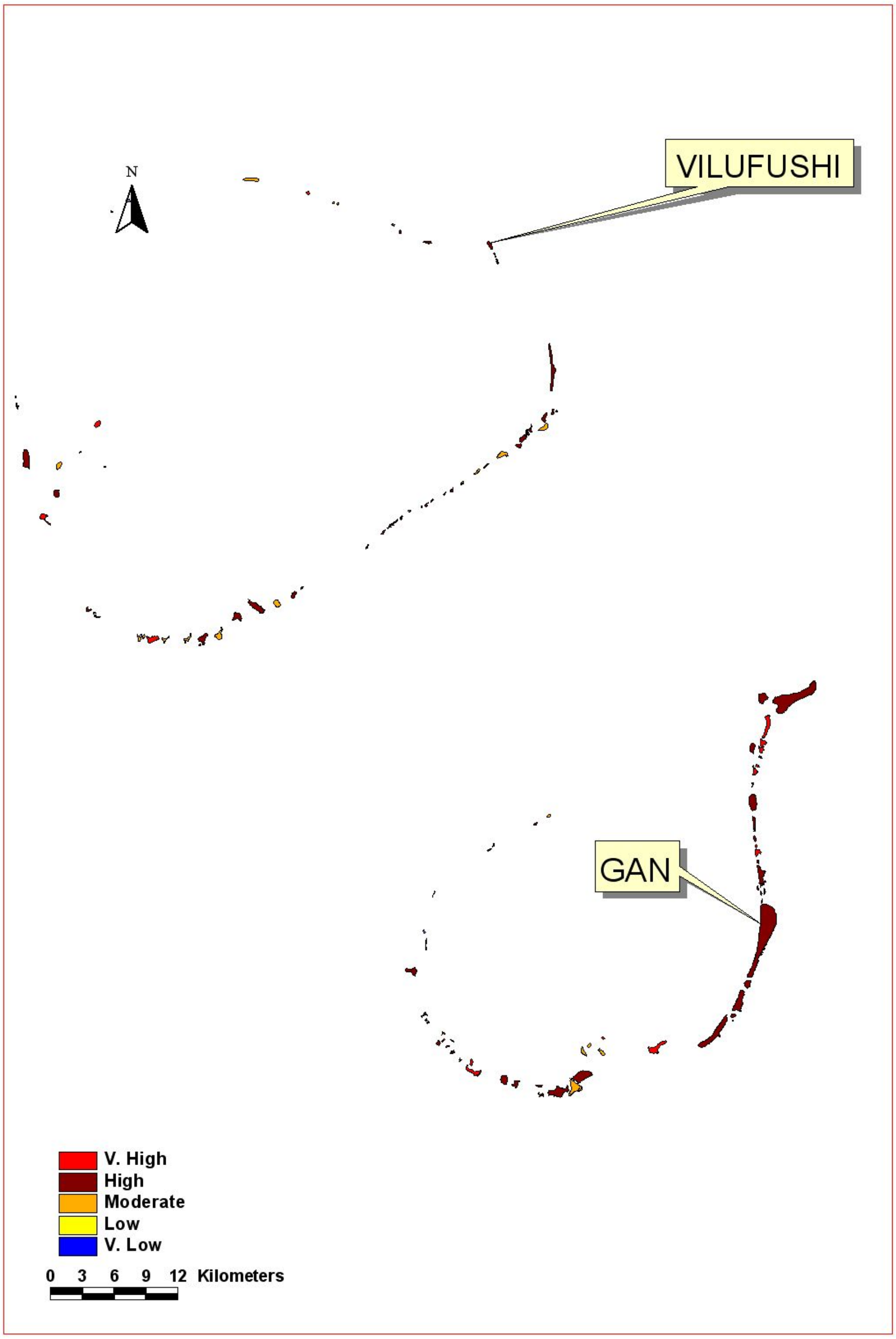


Figure 57; Island Natural Vulnerability of the Islands in the Region 5

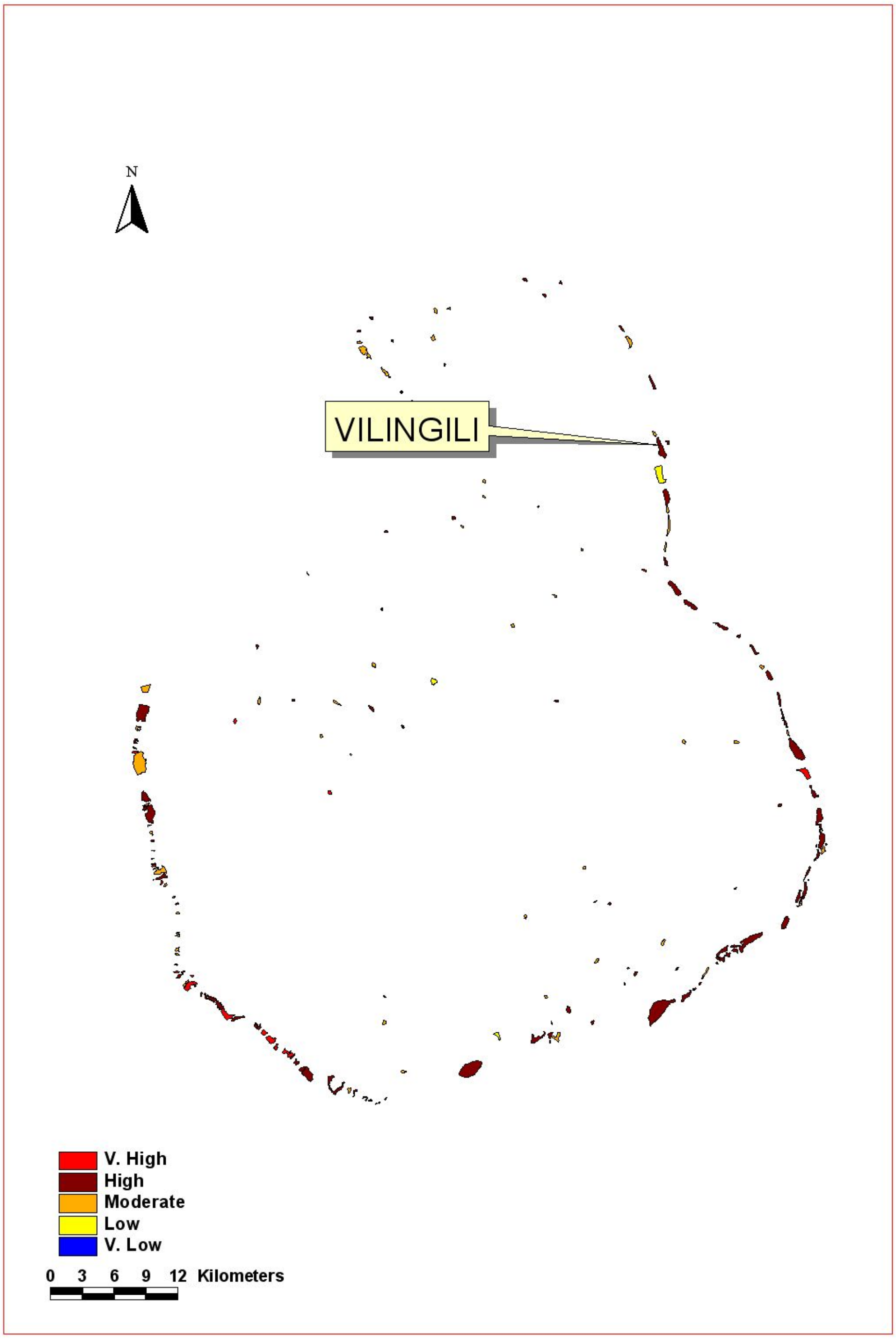


Figure 58; Island Natural Vulnerability of the Islands in the Region 6

Figure 59; Island Natural Vulnerability of the Islands in the Region 7

6.5.5.2 Vulnerable Islands and Safer Islands

The Safer Island Development programme, which the Government of Maldives announced, has identified 11 islands that will be developed as safer islands. The eleven islands which were identified were assessed using the Islands Natural Vulnerability indicator to assess their vulnerability to a disaster event such as a tsunami. Table 19 shows that out of 11 islands that have been identified for the safer islands programme, one island is classified as having very high natural vulnerability and 5 islands have a high natural vulnerability. Map 2 provides the locations of the of these islands. Figure 53, Figure 54, Figure 55, Figure 56, Figure 57, Figure 58 and Figure 59 provides the natural vulnerability of these islands and its locations.

Atoll	Island	Natural Vulnerability
HDh	Nolhivaranfaru	Moderate
Sh	Funadhoo	Moderate
R	Dhuvaafaru	High
B	Goidhoo	Moderate
K	Thulhusdhoo	High
Adh	Maamigili	Moderate
M	Muli	Very High
Dh	Kudahuvadhoo	Moderate
Th	Vilufushi	High
L.	Gan	High
GA	Vilingili	High

Table 19: Islands designated as Safer Islands with the Natural Vulnerability Classification

The research has found that the island natural vulnerability is an important factor which determines the vulnerability of the islands. The fact that a number of islands which have been designated as Safer Islands have a high natural vulnerability, shows that the aspect of the natural vulnerability of island was not considered in the island selection process.

6.6 Summary of results

Figure 60 presents an overview of the hazards and risks in the Maldives and the summary of the factors which determine the natural vulnerability of the islands to a disaster such as a tsunami. Figure 60 also presents some of the trends that were observed in the course of the study.

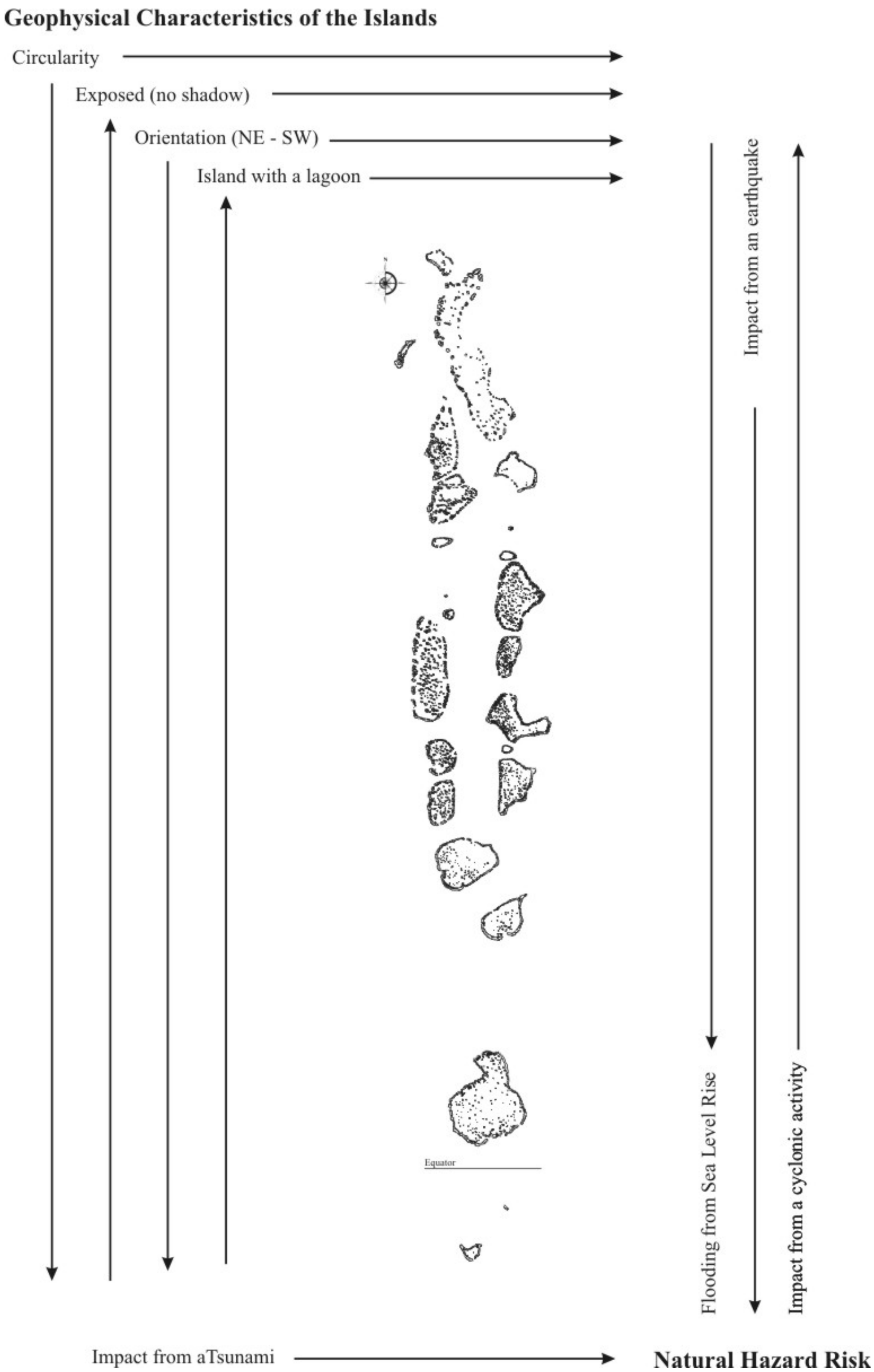


Figure 60: Natural Hazards Trends in the Maldives

7 Use of the Research Findings

The island vulnerability model that has been presented in the study could be used to additionally inform the national sustainable development planning in the Maldives. Following are some of the areas where this model could be integrated to strengthen the existing sustainable development planning tools that are used in the development planning of the Maldives.

7.1 Enhancement of the Safer Island Development Programme

One of the aims of the Safer Island Development Programme is to develop islands as safe centres where the community are at a low risk from disaster events such a tsunami. For the programme to be cost effective, the islands or regions that are chosen for such development need to have a low risk of disaster, i.e. the island natural vulnerability should be low. One way to achieve this is to integrate the island vulnerability index into the island selection criteria of the Safer Island Development Programme which has been described in Figure 20. It is recommended, in the light of the findings of this research, that the Safer Island Development Programme should considering the existing criteria for island selection process as presented in Figure 20 but from a pool of islands where the Island Natural Vulnerability scores below a moderate level.

7.2 Environmental Impact Assessment Process

Environmental Impact Assessment (EIA) is an important tool in the development projects and activities in the Maldives. Environmental impact assessment is a mandatory requirement for all major developments under article 5 of the Environmental Protection and Preservation Act of 1993. The regulations which govern the Environmental Impact Assessment Regulations (2007a) state that the description of the natural environment should be stated by giving details of the beach systems; composition, stability, current, tide and wave dynamics.

The model that has been developed in this study could be used in the EIA process to conduct an assessment of the vulnerability of the island where development projects are undertaken.

One of the components that is missing in the existing environmental impact assessment regulation is the issue of disaster mitigation. In many circumstances, the impact of disasters becomes greater when the developmental activities discount the disaster risk in the development. One of the avenues which is available to check whether appropriate consideration has been made in the development process is the environmental impact assessment process. Hence, it is important to consider reviewing the existing Environmental Impact Assessment Regulations (2007a) to account for disaster mitigation as a prerequisite for implementation of the developmental projects.

7.3 Land Use Planning Process

Land use planning is a mandatory process by the Land Act which is executed by the Ministry of Housing and Urban Development, Maldives. Land use planning is undertaken by the development of a land use plan for each island in the Maldives. These are developed by Ministry of Housing and Urban Development under guidelines developed by them. One area which is lacking from these guidelines is the integration of the disaster risk management into urban development.

The model presented in this research could be used to enhance the understanding of the island environment, which is a prerequisite for safer urban development. Presently there are no tools which can consistently assess the vulnerability of the islands or specific locations of the islands which are susceptible to environmental catastrophe. A better understanding of the existing environment could help to better plan the urban environment and to develop solid land use plans that need not have to frequently undergo major revisions.

7.4 Public Investment Programme

Most of the public infrastructure development projects are implemented through the Public Investment Programme of the Government. The Government of Maldives has established a mechanism for project appraisal which requires that all development projects, funded through the Pubic Investment Programme, be screened by the Project Appraisal Committee (PAC) at the Ministry of Planning and National Development. However, there are no existing tools to assess risk and cost benefit for these projects. For example, a project funded under the Public Investment Programme, the reclamation of Kadholhudhoo island, (MEEW, 2005) implemented at a cost of US$ 30 million, was severely impacted by the Indian Ocean Tsunami (UNEP, 2005) and 3,445 residents of the island had to be evacuated to 11 islands (MPND, 2005b) raising concerns about how the project passed through the appraisal process. Similar circumstances could be minimised by integrating an assessment tool such as the model that has been presented in this thesis as a way to identify the vulnerable islands and to use a cautionary approach in allocating financial resources on very high vulnerable islands.

In planning for sustainable development, it is noted that cost benefit analyses and risk assessments are very rare considered in the Maldives.

8 Further Research

The island vulnerability model has been developed using the data that was collected from the islands of the Maldives following the Indian Ocean Tsunami. Most of the data used in the research has been obtained from National Disaster Management Centre. The data was collected through telephone surveys from the administrative centre at the islands, island offices. The survey forms were designed for rapid assessment; nevertheless, it collected very specific quantitative information from the islands. Hence it is necessary to go to the field to collect geophysical information from a sampled population of islands to help to develop a more accurate model which can then be used for any island environment that is developed on a reef top setting.

9 Conclusion and Recommendation

In the year 2006, the population of the Maldives, which was 298,968, were distributed across 204 administrative islands. The small land area of the island combined with a high population density makes the communities living in these islands very much exposed to natural disaster events such as flooding and tsunami.

The Indian Ocean Tsunami on 26 December 2004 impacted 69 islands, killing 82 people, leaving 26 people missing and 15, 000 people internally displaced making it the worst disaster that has stuck the country in the recorded history. Following the event, the Government of the Maldives announced a Safer Island Development Programme to bring comfort to the population which was severely shaken by the tsunami disaster event. The Safer Island Development Programme presents a holistic development agenda of the country bringing together many sectoral developmental initiatives such as the infrastructure and population consolidation. The Government has unveiled criteria for selecting islands for the Safer Island Development Programme and to date has identified 11 such islands under the programme. One of the limitations of the programme is that a number of islands that have been identified in the programme were severely impacted by the tsunami event, raising concern that an important element has not been taken into account during the island selection process.

This research has been undertaken to identify and study such elements that were not accounted for, to suggest how these elements could be integrated into the present island selection process.

The islands of the Maldives have characteristics which make these vulnerable to disasters such as tsunami. This research has been able to identify the relationship between these characteristics and the Natural Vulnerability of some of the islands using the data collected following the Indian Ocean Tsunami.

The relationship was then applied to all islands to give a Natural Vulnerability Classification to each island. Figure 60 presents an overview of the hazards and risks in the Maldives and the summary of the factors which determine the natural vulnerability of the islands to a disaster such as a tsunami. Figure 60 also presents some of the trends that were observed in the course of the study.

Based on the findings of this study, I would recommend that the Safer Island Development Programme should consider using the existing criteria for island selection process but from a pool of islands where the Island Natural Vulnerability is below a moderate level.

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